CASE STUDY OF INDOOR AIR QUALITY OF HEALTH CARE FACILITIES AND HOSPITALS IN MALAYSIA

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ABSTRACT

Hospitals and healthcare facilities are buildings that require proper design for diverse environment due to their nature. The comfort of occupants and the spread of germs should be consider in the design of such facilities. Airborne diseases have become a serious concern after the spread of influenza H1N1 and Severe Acture Respiratory Syndrome (SARS) viruses. Healthcare facilities, particularly those built in the past, do not consider air as the transport medium for infectious diseases. Most of the recent studies in indoor air control revolve around specialized environments such as isolation rooms and operating theatres. This dissertation studies the indoor air quality (IAQ) of different hospitals for tropical climate.

Standard procedures extracted from ASHRAE standards are applied in the fieldwork to obtain accurate objective measurements and subjective assessments. The objective measurements include measurements of temperature, relative humidity, air velocity, formaldehyde (HCOH), carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compounds (TVOCs), particulate matter (PM) and biological pollutants. For subjective assessment, questionnaires and interviews are conducted to study the background of occupants within the building. Air distributions are simulated with the aid of a CFD tool to support the findings for indoor air quality investigations in healthcare facilities.

The research is divided into four main categories. The first study involves investigating the effect of internal design for air-conditioning mechanical ventilation (ACMV) system on the air distribution and IAQ for a pharmaceutical laboratory. The second study investigates the IAQ profile of a pre-occupied hospital. The third study focuses on the IAQ and thermal comfort between centralized and non-centralized

ACMV systems. Finally, the fourth study examining the use of tea tree oil as a decontamination agent for biological pollutants in humid climates.

The results show that modifications on the ACMV internal design such as location of the diffuser and exhaust are significantly related to the utilization of the room. The diffuser can be used to control and provide a clean work surface for chemical testing in the pharmaceutical laboratory. However, these criteria must be accompanied by proper maintenance of the ventilation system. IAQ audits in hospitals reveal that more occupants under the centralized ACMV systems feel uncomfortable compared to the non-centralized ACMV systems. This indicates that occupants prefer higher temperature and humidity compared with the ASHRAE Standard-55, which promotes energy savings. However, centralized ACMV hospitals exhibit better indoor air quality control for chemical and particulate contaminants. Measurements in all healthcare buildings exhibit a high relative humidity beyond the threshold set by ASHRAE. Humid environment favours the growth of contaminants and colonization of microorganisms, which will accumulate within the facility, especially at the edges of the workspace. Vapourised tea tree oil is sprayed throughout the air-conditioning space via Air-handling Unit (AHU), and the survival of microbial pollutants such as bacteria, fungi and mould is successfully reduced to acceptable levels. Hence, tea tree oil is a potential decontamination agent for air treatment besides the common agent (i.e. hydrogen peroxide). This study shows that indoor environment in Malaysian healthcare facilities still have areas for improvement.

Abstrak

Hospital dan kemudahan kesihatan adalah bangunan yang memerlukan reka bentuk yang sesuai untuk pelbagai persekitaran berdasarkan sifat mereka. Keselesaan penghuni dan penyebaran kuman harus dipertimbangkan semasa mereka bentuk sistem penghawa dingin. Penyakit bawaan udara telah menjadi satu kebimbangan yang serius selepas penyebaran selesema H1N1 dan Sindrom Pernafasan (SARS) virus. Kebanyakan kajian terkini dalam kawalan udara dalaman berkisar persekitaran khusus seperti bilik pengasingan dan teater operasi. Disertasi ini mengkaji kualiti udara dalaman (IAQ) dalam pelbagai jenis hospital, termasuk sistem pengudaraan, keadaan tertutup dan keselesaan terma.

Tatacara piawai yang diekstrak dari piawai ASHRAE digunakan semasa kerja lapangan untuk mendapatkan ukuran yang objektif dan penilaian subjektif yang tepat. Pengukuran objektif dalam kajian ini merangkumi pengukuran suhu, kelembapan relatif, halaju udara, formaldehid (HCOH), karbon dioksida (CO_2), karbon monoksida (CO), bahan kimia organik meruap (TVOCs), jirim zarahan (PM) dan bahan pencemar biologi. Soal selidik dan temubual dijalankan untuk penilaian subjektif bagi mengkaji latar belakang penghuni di dalam bangunan. Profil halaju dan pengagihan pencemaran telah disimulasi dengan menggunakan Perkomputeran Dinamik Bendalir (CFD) bagi menyokong dapatan kajian untuk siasatan IAQ dalam kemudahan penjagaan kesihatan.

Kajian dibahagikan kepada tiga kategori utama. Kajian pertama melibatkan penyiasatan kesan reka bentuk dalaman bagi sistem HVAC terhadap corak aliran udara, pengedaran jirim zarahan, dan keselesaan terma. Kajian kedua merangkumi penyiasatan penggunaan minyak pokok teh sebagai ejen yang berpotensi untuk mendekontaminasikan bahan pencemar biologidi dalam iklim lembap. Akhirnya, kajian

yang ketiga tertumpu kepada kualiti udara tertutup dan keselesaan terma antara sistem penghawa dingin berpusat dan tidak berpusat (AC), yang terdiri daripada pengukuran keselesaan terma, gas kimia dan jirim zarahan dalam empat buah hospital.

Hasil kajian menunjukkan bahawa pengubahsuaian reka bentuk dalaman seperti kedudukan peresap dan ekzos HVAC amat berkaitrapat dengan penggunaan sesebuah bilik kerana reka bentuk dalaman boleh digunakan untuk mengawal dan menyediakan permukaan kerja yang bersih untuk melaksanakan ujian kimia di makmal farmaseutikal. Walaubagaimanapun, rekabentuk dalaman harus disertakan dengan penyelenggaraan sistem pengudaraan. Hasil kajian kesemua bangunan penjagaan kesihatan menunjukkan kelembapan relatif yang tinggi di luar ambang yang telah ditetapkan oleh ASHRAE. Persekitaran yang lembap menggalakkan pertumbuhan bahan cemar serta pengkolonian mikroorganisma, yang mudah berkumpul terutamanya di pinggir ruang. Minyak pokok teh mengewap telah disembur di seluruh ruang udara dingin melalui Unit Pengendalian Udara (AHU), dan kemandirian pencemaran mikrob seperti bakteria, kulat dan kulapuk berjaya dikurangkan kepada tahap yang boleh diterima. Oleh itu, minyak pokok teh merupakan agen dekontaminasi yang berpotensi untuk merawat udara selain daripada hidrogen peroksida. Audit IAQ di hospital menunjukkan bahawa lebih banyak penghuni berasa tidak selesa di bawah sistem AC berpusat berbanding dengan sistem AC bukan berpusat. Hospital yang menggunakan sistem SC berpusat menunjukkan kualiti kawalan udara tertutup yang lebih baik untuk bahan cemar kimia dan zarah. Ini menunjukkan bahawa penghuni lebih menggemari suhu dan tahap kelembapan yang lebih tinggi berbanding dengan nilai yang dicadangkan oleh Piawai ASHRAE 55, yang menggalakkan penjimatan tenaga. Oleh itu, dapat disimpulkan bahawa masih terdapat ruang yang perlu diperbaiki untuk persekitaran tertutup di dalam kemudahan penjagaan kesihatan di Malaysia.

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CHAPTER 7 TEA TREE OIL DECONTAMINATION

APPENDIX

NOMENCLATURE

a*	Slope coefficient
ACGIH	American Conference of Industrial Hygienists
ACH	Air changes per hour
ACMV	Air-Conditioning Mechanical Ventilation
AHU	Air-Handling Unit
AIA	American Institute of Architecs
ASHRAE	American Society of Heating, Refigerating and Air-Conditioing Engineers
BRI	Building Related Illness
CCU	Coronary Care Unit
CDC	Centre of Disease Control
CFD	Computational Fluid Dynamics
CFM	Cubic feet per minute
CFU	Cubic feet unit
CIBSE	Chartered Institution of Building Services Engineers
C_m	Mean comfort vote
CO	Carbon monoxide
CO_2	Carbon dioxide
COHb	Carboxylhemaeglobin
CU	Chemistry Unit
DOE	Department of the Environment
DOSH	Department of Occupational Safety and Health
ECJRC	European Commission Joint Research Centre
ENV	Ministry of Environmental
EPA	Environmental Protection Agency
FS	Federal Standard
HAI	Hospital Acquired Infection

HCOH	Formaldehyde
HEPA	High efficiency particulate air
HICPAC	Healthcare Infection Control Practices Advisory Committee
HTM	Health Technical Memorandum
HVAC	Heating, Ventilating and Air-Conditioning
IAQ	Indoor Air Quality
ICU	Intensive Care Unit
ID	Identity
IEH	Institute for Environment and Health
IEQ	Indoor Environmental Quality
IEST	Institute of Environmental Science and Technology
ISO	International Organization for Standardization
IT	Information Technology
KU	Chromatography Unit
M	Relative molar mass of contaminant
MAK	Maximum workplace concentration
MCS	Multiple Chemical Sensitivity
MERV	Minimum efficiency reporting value
MMAD	Mass Median Aerodynamic Diameter
MOH	Ministry of Health
MRSA	Methicillin-resistant Staphylococcus aureus
NEA	National Environment Agency
NIOSH	National Institute of Occupational and Health
NVOC	Non-volatile organic compounds
OSHA	Occupational Safety and Health Administration
OT	Operating theatre
p	Mixture pressure, kPa
PAH	Polycyclic Aromatic Hydrocarbons

PCA	Plate Count Agar
PM	Particulate matter
PM_{10}	Particulate matter smaller than 10 micron
ppb	Parts per contaminant by volume per billion parts of air by volume
ppm	Parts per contaminant by volume per million parts of air by volume
Q_{CU}	Flow rate for Chemistry unit
Q_{KU}	Flow rate for Chromatography unit
RH	Relative humidity
SARS	Severe Acture Respiratory Syndrome
SBS	Sick Building Syndrome
SDA	Sabouraud Dextrose Agar
SOC	Special Outpatient Clinic
SSI	Surgical Site Infection
SVOC	Semi volatile organic compounds
T_c	Comfort temperature
T_{gm}	Mean internal temperature
TVOC	Total volatile organic compounds
UK	United Kingdom
ULPA	Ultra-low penetration air
US	United States
VOC	Volatile organic compounds
VVOC	Very volatile organic compounds
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.0 Overview

This section describes the background of indoor air quality study and the application of air-conditioning mechanical ventilation in indoor air control. The research gap in this study is identified and presented. The objectives of the study and the organization of this dissertation are also presented in this section.

1.1 Research Background

Air-conditioning mechanical ventilation (ACMV) systems were first designed serve for process applications such as textile and printing industry for production purposes. The systems were later used for comfort applications, which are aimed to provide a relatively constant building environment for occupant comfort despite a change in outdoor environment. As one of the most important institutions in the nation, ACMV systems are then installed in hospitals and other healthcare facilities. Hospital air-conditioning plays a significant role other than simply providing thermal comfort to occupants. Patients with different illnesses require different indoor conditions (ASHRAE, 2004). Proper air-conditioning indoor condition may be used as a treatment in patients' therapy; and in some circumstances, it is the major treatment (ASHRAE, 2007b). Therefore, healthcare facilities related to the process applications with the aim of providing a suitable environment for a process are being carried out.

ACMV systems are used for controlling the air temperature and relative humidity level within a space, as occupants spend more time in enclosed spaces. Hence, occupants are subject to long-term exposure to indoor contaminants. An investigation

carried out amongst US residents showed that on average, 88% individuals spent their day inside buildings, 7% in vehicles and only 5% participants spent their time outdoor (Robinson and Nelson, 1995). Therefore, health problems associated with indoor air arise as a common health issue (Ledford and Lockey, 1994; Rosenstock and Cullen, 1994; Seltzer, 1995). The subjective health complaints commonly faced by occupants in buildings are known as "Sick Building Syndrome", which includes headaches, fatigue, rash, dry eyes, dry skin, upper-respiratory irritative symptoms, and general symptoms associated with a particular building (Burge, 2004; Redlich *et al.*, 1997). Indoor health issues associated with indoor-air microorganisms, such as legionnaire's disease, viral infection, and tuberculosis, which are infectious diseases are well recognised (Husman, 1996).

In recent years, the increase in global fuel costs has driven the modifications in building design to be more energy-efficient and "airtight" (Jones, 1998). In line with this, the number of SBS cases increased rapidly as "airtight" buildings replace naturally ventilated buildings (Redlich *et al.*, 1997). Advances in construction technology have led to a much greater use of synthetic building materials, for improved insulation and construction cost management (D'Amato *et al.*, 1994). Radon and asbestos building materials are examples of such potential risk (Lockey and Ross, 1994). These changes provide an environment in which airborne contaminants are readily produced and may build up to substantially higher concentrations than that typically encountered outdoor (Teichman, 1995).

Many studies were carried out on hospital indoor air quality in different countries (Argiriou *et al.*, 1994; Brenniman and Allen, 1993; Kelland, 1992; Leung and Chan, 2006; Obbard and Fang, 2003). A number of studies focused on specific hospital

environments such as operating and isolation rooms (Cheong and Phua, 2006; Dascalaki *et al.*, 2009; Dascalaki *et al.*, 2008; Dharan and Pittet, 2002; Richmond-Bryant, 2009; Shih *et al.*, 2007).

Compared to other countries, less research has been carried out to study IAQ within healthcare facilities located in tropical climates such as Malaysia. Recent research for hospitals in Malaysia include an IAQ study on the source of problem in a new hospital (Lian *et al*., 2007), thermal comfort study in a few hospitals to develop an adaptive model (Yau and Chew, 2009) and study on tuberculosis transmission in a hospital's indoor environment (Shakri *et al*., 2011; Shakri *et al.*, 2012). From previous studies related to IAQ in healthcare facilities, it is evident that there is a lack in comparative studies on IAQ profile for different healthcare buildings.

This thesis discusses on a field study carried out in a few healthcare facilities in Malaysia. The study focuses on IAQ audits in different healthcare buildings, study of the ACMV system design with the aid of simple CFD model, and a field study of microbial decontamination of indoor air using vapourized tea tree oil.

1.2 Research Objectives

This study focuses on the assessment of Indoor Air Quality (IAQ) and determines the possible solutions for improvement.

In this study, IAQ audits are carried out with both objective measurements (chemical gaseous pollutants, thermal comfort, particulate matter and biological pollutants) and subjective measurements (questionnaire survey of occupants) to identify the IAQ profile of the research facilities, their environmental effects towards occupants and identify the sources which results to its deviation from the recommended standards.

This study focuses on:

1. An IAQ field study in a pharmaceutical laboratory in Petaling Jaya, Malaysia, which includes CFD simulations to study the air distribution.
2. An IAQ assessment and study of biological decontamination using vapourized tea tree oil as a decontamination agent in a newly-commissioned healthcare facility in Sarawak, Malaysia.
3. An IAQ field study in four hospitals which utilize centralized and non-centralized air-conditioning systems.

1.3 Significance of the Study

This study has three key scientific contributions:

i. Measurements of indoor air quality parameters and survey from occupants for selected healthcare facilities to study the IAQ profiles for Malaysian hospitals. (Pharmaceutical laboratory, Petaling Jaya; Four hospitals in Selangor and Kuala Lumpur area. The hospital utilise centralised and non-centralised air-conditioning systems.)
ii. Possibility of decontaminating microbial contaminants using vapourized tea tree oil.
iii. To carry CFD investigation of air distribution in the pharmaceutical laboratory.

The immediate impact of the outcomes is to confirm and if necessary enhance the indoor air quality of hospitals to reduce infectious particle transport that may be caused by heavy particles or microbial contaminants. This study also attempt to understand the thermal comfort guidelines that are suitable for use in tropical climates, which may support the recommendations stipulated in the ASHRAE Design Manual and the upcoming ASHRAE standard. The outcomes anticipated from this study are established air distributions of the design features such as pharmaceutical laboratory in order to provide clean workspace for drug or chemical testing.

1.4 Outline of the Dissertation

Chapter One is the introduction of the dissertation. In this chapter, the research background and objectives are presented in brief.

Chapter Two presents the literature review of the research.

Chapter Three discusses the research methodologies used in Chapters Four through Seven.

Chapter Four presents the indoor air quality audits in a pharmaceutical laboratory building.

Chapter Five discusses the indoor air quality assessment in a newly commission hospital in East Malaysia.

Chapter Six discusses the indoor air quality audits in four hospitals with centralized and non-centralized air-conditioning systems.

Chapter Seven shows the possibility of decontaminating microbial pollutants using vapourized tea tree oil.

Chapter Eight presents the general conclusion and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This section presents the literature review on indoor air quality for healthcare buildings. This review covers indoor air contaminants, thermal comfort, Sick Building Syndrome and ventilation design. Standards and guidelines governing ventilation design for indoor air quality of buildings are also studied. Discussions regarding microbial disinfection are also presented.

2.2 Indoor Air Contaminants

2.2.1 Non-Biological Sources

Outdoor air may be a contributor of non-biological pollutants, particularly for buildings situated in urban areas and within the vicinity of industrial zones or nearby streets with serious traffic. Contribution of outdoor contaminants to indoor air quality maybe determined by a few factors, which comprise the nature of ventilation use, ventilation rate, and the nature of the contaminants in question (Wanner, 1993). Table 2.1 shows the most important outdoor sources which contribute to indoor air pollution based on UK estimates. Reactive gases such as ozone have a tendency to occur at lower concentrations compared with outdoors as such gases react rapidly with surfaces of indoor environment (Wallace, 1987). Non-reactive gases may possibly gather indoors, with greater exposure compared to outdoor.

Table 2.1: Outdoor sources of major indoor air pollutions (DOE, 1997)

Pollutant	Percentage of emissions associated with industry	Percentage of emissions associated with transport
Benzene	32	65
Carbon monoxide (CO)	3	90
Lead (Pb)	31	60
Oxides of nitrogen (NO_2)	38	49
Particulates (PM_{10})	56	25
Sulphur dioxide (SO_2)	90	2
Volatile organic compounds (VOC)	52	34
Ozone (O_3)	Arises from atmospheric chemical reactions	

A detailed investigation on the influence of outdoor pollutants on indoor air quality is required by considering their chemical characteristics and reaction when occupying indoor environment. For example, radon is considered as it is an important threat when found indoors (Jones, 1999).

Indoor activities such as heating and cooking are the main activities which produce indoor gases and smoke. This raises the issue of removing combustion by-products while retaining heat, especially in colder climates (Burr, 1997). Most of the pollutants arise from combustion, and indoor pollution such as smoke was dominated by coal and wood during heat production (Wallace, 1997). Nowadays in some countries, for example, China and eastern Europe, the use of wood and coal still remains a primary fuel (Lan *et al.*, 1993; Zhang and Smith, 2007). In contrast, in developed countries such as US and western Europe, the use of natural gas and electricity has greatly replaced the traditional fuels (e.g. wood and coal) during heating (Lambert, 1997). This can be supported by data collected from US residential homes, where one-third of them uses

gas for heating and cooking (Hines *et al.*, 1993). Severe indoor air problems occur only when the use of unvented facilities or those that are faulty or improperly installed (Nagda *et al.*, 1996). However, almost 50% people, in which almost all are from developing countries, still rely on coal and biomass in the form of wood, dung and crop residues that are burnt in simple stoves which result in very incomplete combustion (Bruce *et al.*, 2000).

As conventional fuels such as wood and coal are substituted by electricity and natural gas, cigarette smoking arises as an important source for indoor combustion. Tobacco smoke is an aerosol containing several thousand substances that occur as particles, vapors and gases (Wynder and Hoffmann, 1968). Exposure to cigarette smoke has been related with a variety of acute and chronic health problems (Hackshaw *et al.*, 1997; Hecht, 1999; Hofhuis *et al.*, 2003; Janerich *et al.*, 1990; Mannino *et al.*, 2001; Repace and Lowrey, 1980).

Materials used in building structures are other important sources of non-biological contaminants. A great amount of chemical substances found in indoor air originate from construction materials used in buildings, such as solvents, wood preservatives and paint (Andersen *et al.*, 1975; ECJRC, 1997; Mølhave, 1982). Indoor pollutants from deteriorating materials are often difficult to measure due to their relatively low concentrations and diffuse characteristics (Wanner, 1993). These indoor sources are often influenced by climatic factors such as temperature and relative humidity (van Netten *et al.*, 1989). Therefore, health risks arise from contaminants related to building

materials, depending on their concentration and nature.

Table 2.2: Acceptable limits of local and international standards for indoor air

	International Standards					Singapore Guideline **(ENV)**	Malaysia Guideline **(DOSH)**
	ASHRAE	**ACGIH**	**NIOSH**	**OSHA**	**MAK**		
Formaldehyde (ppm)	-	0.3	0.016 0.1(15min)	0.75 2 (15min)	0.3	0.1	0.1
Carbon Monoxide (ppm)	9(8hr)	25(8hr)	35(8hr)	35(8hr)	30	9	10
Carbon Dioxide (ppm)	1,000	5,000	5,000	10,000	5,000	1,000	1,000
Total volatile organic compounds (ppm)	-	-	-	-	-	3	3
Total bacteria count (CFU/m^3)	-	-	-	-	-	500	-
Total yeast and Mould (CFU/m^3)	-	-	-	-	-	500	-
Respirable particulate (< 10μm) (mg/m^3)	-	10	-	-	4	0.15	0.15
Dry bulb temperature (℃)	23-27		-	-	-	22.5-25.5	-
Relative humidity (%RH)	30-60%		-	-	-	< or = 70%	-

A comparison between the acceptable limits for various pollutants specified by local guidelines in Malaysia with neighboring country (e.g. Singapore), and those established by other international standards are shown in Table 2.2. The common pollutants which will be audited for indoor air quality in buildings are formaldehyde (HCOH), carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compounds (TVOCs), total bacteria, yeast and mould counts, and respirable particles. From the above mentioned pollutants, it is observed that there are no standards for TVOC and microbial contaminants. The Malaysian and Singapore guidelines for TVOC' threshold limits are based on Toluene from the studies carried out by Molhave (1991).

2.2.1.1 Units of Measurement

Concentrations of gaseous contaminants are usually expressed in the following units:

ppm = parts of contaminant by volume per million parts of air by volume

ppb = parts of contaminant by volume per billion parts of air by volume

1000 ppb = 1 ppm

mg/m^3 = milligrams of contaminant per cubic meter of air

$\mu g/m^3$ = micrograms of contaminant per cubic meter of air

The conversion between ppm and mg/m^3 are as follows:

$$ppm = \left[8.309\ (\frac{273.15+t}{Mp})\right](mg/m3) \quad \text{----------(2.1)}$$

$$mg/m3 = [0.1204\ (Mp)](273.15 + t)(ppm) \quad \text{----------(2.2)}$$

Where,

M = relative molar mass of contaminant

p = mixture pressure, kPa

t = mixture temperature, ℃

The concentration data are often reduced to standard temperature and pressure (i.e., 25 ℃ and 101.325kPa), whereby,

$$ppm = \left(\frac{24.45}{M}\right)(\frac{mg}{m^3}) \quad \text{----------(2.3)}$$

Equations (2.1) through (2.3) are firmly true only for ideal gas. However, these equations are generally suitable for dilute vapourous contaminants dispersed in ambient air.

2.2.1.2 Carbon Monoxide (CO)

Exposure sources: Carbon monoxide (CO), which is also known as carbonous oxide, is a tasteless, odourless, and colourless poisonous gas produced by the incomplete combustion of fuels (IEH, 1996). CO will form when there insufficient oxygen (O_2) during combustion to produce carbon dioxide (CO_2), such as when an internal combustion engine operates indoors or in an enclosed place or when operating a cooking stove. The possible sources for CO may originate from combustion components such as gas or coal heaters, water heaters and gas stoves (Gold, 1992). High levels of CO may arise from outdoor vehicle exhaust into the buildings. Tobacco smoking is an additional source of temporary CO pollution (Sterling, 1991). The use of gasoline-powered electrical generator during electric service disruption, and burning of charcoal briquettes during winter storm may result in short-term problems of producing high levels of indoor CO concentration (Houck and Hampson, 1997). Paint stripper contains a substance known as methylene chloride which can metabolize within the body to form CO, and its use can lead to a significant dose of CO, even in well-ventilated rooms (Gold, 1992)

Exposure: Generally, the CO concentrations indoors are lower than outdoors in the absence of emission sources. A survey on the personal CO exposures of 100 non-smoking adults, residential exposures by US Environmental Protection Agency (EPA) revealed a rather low concentration, ranging from 2 to 4 ppm (approximately 2.3 – 4.7 $\mu g/m^3$) (Akland *et al.*, 1985). The hourly concentration of CO is generally around

6 ppm (6.9 μg/m^3) when the gas stove is in operation, and does not often exceed 12 ppm (13.8 μg/m^3) (Samet *et al.*, 1987).

Measuring parameter: The high affinity for oxygen-carrying proteins inside CO influences its poisonous properties such as haemoglobin and myoglobin (Coultas and Lambert, 1991). CO displaces oxygen due to the high affinity for hemoglobin compared with oxygen (approximately 200 times greater), CO displaces oxygen, forming carboxyhemaeglobin (COHb), which lowers the oxygen carrying capacity of the blood (Roughton and Darling, 1944). Therefore, the health effects of exposure to CO are normally described relative to COHb levels (Madany, 1992). In non-smoking individuals unexposed to environmental CO, the blood COHb levels are usually around 0.5% (Lambert, 1997).

Health effects: Acute low-level exposures of CO can also causes various symptoms of neuropsychological impairment. This was shown in a study for exposure of CO produced by residential stoves (up to 2.5h), where respondents exhibited a decline in their planning and learning abilities, along with attention and concentration spans (Amitai *et al.*, 1998). Chronic exposure (at 10-30% COHb) often produces symptoms that are easily misdiagnosed or unnoticed, such as fatigue, headache, nausea and dizziness (Stewart *et al.*, 1970). In addition, animal studies showed evidence that maternal exposure to CO may results in some levels of fetal damage (Longo, 1977). Due to the high affinity of CO compared to oxygen, organs with high oxygen requirements will face most toxic acute effects when exposed to CO, such as the brain

and heart. At moderate concentrations of CO, adverse cardiovascular effects may be observed amongst susceptible individuals (Dahms *et al.*, 1993). Lambert (1994) studied 20 non-smoking men with ishaemic heart disease and found that the probability of occurrence of an episode of *myocardial ischemia* was 2.1 times higher at COHb levels of 2% relative to those below 1%.

The greatest risk of severe CO poisoning arises from defective combustion appliances, malfunctioning or blocking of external vents (Howell *et al.*, 1997), which result in convulsions and fainting (COHb 50-60%), whilst higher exposures can lead to coma or death. An average of 60 deaths related to accidental CO poisoning is found annually in England and Wales (Burr, 1997), with similar rates observed at USA (Cobb and Etzel, 1991). Individuals who survive from acute CO poisoning may still exhibit neurological and psychological symptoms after exposure, especially if the individuals fall into unconsciousness (Choi, 1983).

Standards and guidelines: The recommended values of exposure for carbon monoxide should not exceed 9 ppm for eight-hour time weighted average airborne concentration as indicated by AHSRAE standard (ASHRAE, 2007a), Singapore guideline (ENV, 1996) and Raatschen (1990). The recommended value is 10 ppm based on the Malaysian Code of Practice for Indoor Air Quality (DOSH, 2005). The National Institute of Occupational and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) suggest a value of 35 ppm as the threshold limit (NIOSH, 2004;

OSHA); whereas the value is 35ppm for MAK (MAK, 2000) and 25ppm for ACGIH (ACGIH, 2005).

2.2.1.3 Carbon Dioxide (CO_2)

Exposure sources: Carbon dioxide (CO_2) is an odourless and colourless gas, which a source of indoor pollutants emitted by humans and correlates with human metabolic activity. Emissions of CO_2 by humans constitute a major portion of indoor pollutants of CO_2, in the absence of other sources (e.g. burning fuel) (Wanner, 1993). Besides human respiratory, the main contribution of CO_2 arises from combustion such as kerosene, gas and wood or coal fuelled appliances (Moriske *et al.*, 1996).

Exposure: In the absence of external sources, CO_2 concentrations range between 700 to 2000 ppm (approximately 3657 mg^{-3}). These indoor concentrations can exceed 3000 ppm (5486 mg^{-3}) during the use of unvented appliances (Arashidani *et al.*, 1996).

Health effects. CO_2 is a simple asphyxiant, which may act as a respiratory irritant (Maroni *et al.*, 1995). Typical indoor to outdoor concentrations ratio for CO_2 are within the range of 1 to 3 for most environments, significant health problems only occur when exposed to extremely high CO_2 levels (above 30,000 ppm or 54860 mg^{-3}) (NASA, 1973). Studies on the effect of CO_2 can be traced back to 1858 by Pettenkofer, which states that moderate concentrations of CO_2 can cause stuffiness and discomfort (Pettenkofer, 1858). Respiration can be affected to some extent when concentrations

exceed 15,000 ppm (27430 mg^{-3}). Exposure above 30,000 ppm will cause some health symptoms such as nausea, dizziness and headaches (Schwarzberg, 1993). The concentrations of CO_2 also affect the perception of motion, by moderating the activity of cells within the visual cortex (Yang *et al.*, 1997).

Standards and guidelines: Singapore guidelines (ENV, 1996), ASHRAE standard 62.1 (ASHRAE, 2007a) and Malaysia guidelines (DOSH, 2005) recommend a threshold limit of 1000 ppm for carbon dioxide for an eight-hour time weighted average airborne concentration. The other threshold limits are 5000 ppm (ACGIH, 2005; MAK, 2000; NIOSH, 2004) and 10,000 ppm (OSHA).

2.2.1.4 Total Volatile Organic Compounds (TVOC)

Definition: Organic compounds refer to chemical compounds that contain at least one carbon and a hydrogen atom in its molecular structure. Organic compounds are further classified into a range of categories, which comprise very volatile organic compounds (VVOC), volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and non-volatile organic compounds (NVOC). The details of these compounds are shown in Table 2.3.

Table 2.3: Classification of indoor organic compounds by volatility (WHO, 1989)

Description	Abbreviation	Boiling point range, ℃
Very volatile (gaseous) organic compounds	VVOC	0 to 50-100
Volatile organic compounds	VOC	50-100 to 240-260
Semi volatile organic compounds (pesticides, polynuclear aromatic compounds, plasticizers)	SVOC	240-260 to 380-400
Non-volatile organic compounds	NVOC	

Exposure sources: VOC have a high vapour pressure at ordinary, room-temperature environments, usually ranging between 50 to 260℃ (Maroni *et al.*, 1995). Materials containing VOC and similar kinds demonstrate the desirable characteristics of being cost-effective, and having good insulation properties, fire-resistance and ease of installation. These characteristics promote their uses in the building industry (Burton, 1997). Table 2.4 display a list of familiar VOC found indoors. 350 VOC out of a total of approximately 900 chemicals and biological substances are found in indoor air, been measured at concentrations exceeding 1 ppb (Brooks *et al.*, 1991).

Table 2.4: Sources of common VOC in indoor air (Maroni *et al.*, 1995)

Sources	**Examples of Typical Contaminants**
Consumer and commercial products	Aliphatic hydrocarbon (n-decane, branched alkanes), aromatic hydrocarbons (toluene, xylenes), halogenated hydrocarbons (methylene chloride), alcohols, ketones (acetone, methyl ethyl ketone), aldehydes (formaldehyde), esters (akyl ethoxylate), ethers (glycol ethers), terpenes (limonene, alpha-pinene).
Paint and associated supplies	Aliphatic hydrocarbons (n-hexane, n-heptane), aromatic hydrocarbons (toluene), halogenated hydrocarbons (methuene chloride, propylene dichloride), alcohols, ketones (methyl ethyl ketone), esters (ethyl acetate), ethers (methyl ether, ethyle ether, buthyl ether).
Adhesives	Aliphatic hydrocarbons (hexane, heptane), aromatic hydrocarbons, halogenated hydrocarbons, alcohols, amines, ketones (acetone, methyl ethyl ketone), esters (vinyl acetate), ethers.
Furnishings and clothing	Aromatic hydrocarbons (styrene, brominated aromatics), halogenated hydrocarbons (vinyl chloride), aldehydes (formaldehyde), ethers, esters.
Building materials	Aliphatic hydrocarbons (*n*-decane, *n*-dodecane), aromatic hydrocarbons (toluene, styrene, ethylbenzene), halogenated hydrocarbons (vinyl-chloride), aldehydes (formaldehyde), ketones (acetone, butanone), ethers, esters (urethane, ethylacetate).
Combustion appliances	Aliphatic hydrocarbons (propane, butane, isobutane), aldehydes (acetaldehyde, acrolein).
Potable water	Halogenated hydrocarbons (1,1,1-trichloroethane, chloroform, trichloroethane).

Exposure: Indoor VOC concentrations are usually five times greater than outdoor air,; however the values are still well below the odour threshold limit (Wallace, 1991a). Indoor air VOCs contain a great number of chemical substances with different range of concentrations, depending on the conditions of the indoor environment (Brown *et al.*, 1994; Mølhave, 1979; Shah and Singh, 1988). Therefore, most of the guidelines and reports use the level of Total Volatile Organic Compounds (TVOCs) rather than the concentrations of individual VOCs (ECJRC, 1997). A study in the UK by Brown and Crump (1996) on 179 residential houses revealed that TVOC concentrations were within the range of 200 - 500 $\mu g/m^3$. These findings were supported by research in the US (Hartwell *et al.*, 1987), Denmark (Wolkoff *et al.*, 1991), Sweden (Norbäck *et al.*, 1993) , and Germany (Aldlkofer *et al.*, 1993).

Health effects: Exposure to volatile organic compounds may lead to acute and chronic health effects. Individuals with asthma and respiratory complaints are particularly vulnerable to low dose VOC exposures compared to others, such as nocturnal breathlessness (Wieslander *et al.*, 1996). In addition, low dose VOCs can lead to fatigue, headache, drowsiness, and confusion as shown by Otto *et al. (*1992) for 22 VOCs at 25 $\mu g/m^3$.

Animal and experimental studies on the toxicity of VOCs toxicity at high concentrations do not exhibit health impact on indoor environments, which usually have low VOC levels. Studies which investigated high concentrations of VOCs showed that many VOCs are powerful narcotics, and can depress the central nervous system (Maroni

et al., 1995). Other arising risks were irritation of the eyes and respiratory tract, causing allergic reactions involving the skin, eyes and lungs. Due to the similarities of these symptoms, VOCs are usually being identified as one of the causes of Sick Building Syndrome (Mølhave, 1991b). At extreme concentrations, some VOCs may lead to impaired neuro-behavioural function (Burton, 1997), as well as coma, convulsions and perhaps death at levels exceeding 35,000 $\mu g/m^3$ (Sandmeyer, 1982). Animal studies revealed that several VOCs commonly found indoors may lead to cancer when exposed to high concentrations of VOCs. These indoor VOCs include benzene, methylene chloride, vinylidine chloride, carbon tetrachloride, ethylene dibromide chloroform, and p-dichlorobenzene (Wallace, 1991b).

Wolkoff *et al.* (1997) proposed that chemical reactions involving VOCs were more important than their direct exposure, due to the fact that SBS contains VOCs at low dose levels, in which the levels are lower than those required to induce the symptoms. Studies on SBS showed that SBS symptoms were caused by a few chemicals other than VOCs (Reiss *et al.*, 1995), such as indoor ozone (Groes *et al.*, 1996), particles (Schneider *et al.*, 1994) and nitrogen dioxide (Grosjean *et al.*, 1992).

Standards and guidelines: Presently, there are no precise guidances and standards TVOC in indoor air. For TVOC, the work by Mølhave (1991) based on Toluene is generally considered as an acceptable limit. The threshold value for TVOC based on the Malaysian Code of Practice on IAQ and Singapore guidelines is 3 ppm (DOSH, 2005; ENV, 1996).

2.2.1.5 Formaldehyde (HCOH)

Exposure sources: Formaldehyde gas is one of the most common aldehydes found daily. Formaldehyde is often considered separately from other volatile compounds since the gas chromatography methods normarlly used for VOC analysis are unable to detect formaldehyde (Maroni *et al.,* 1995). Formaldehyde is a colourless gas with a pungent odour at room temperature. The primary source of formaldehyde in indoor air are building materials such as particle boards, resins, medium-density fibreboards, carpeting, plywood and adhesives (Hines *et al.*, 1993).

Exposure: Outdoor formaldehyde concentration levels are usually less than 0.1 ppm (Maroni *et al.,* 1995). The formaldehyde emission rate in indoor environments varies according to indoor environment conditions such as humidity and temperature (van Netten *et al.,* 1989). Formaldehyde concentration in indoor environments usually exceed those observed outdoors. The study of Anderson *et al.* (1975) on 23 Danish homes revealed an average formaldehyde concentration of 0.5 ppm (0.6 mg m^{-3}), with a range from 0.07 to 1.9 ppm (0.08 – 2.28 mg m^{-3}). Similar findings were subsequently reported in Germany by Prescher and Jander (1987), in Finland by Niemala *et al.* (1985) and in USA by Breysse (1984).

Health effects: Adverse health effects from formaldehyde exposure may occur from inhalation or direct contact (Jones, 1999). Table 2.5 shows a collection of acute health impacts associated with different concentrations of formaldehyde. Exposure of less than 1 ppm to formaldehyde results in coughing, sneezing and minor eye irritations,

although these symptoms often subside rapidly after exposure (Koeck *et al.*, 1997). Studies showed that formaldehyde vapour also serve as skin irritants (Eberlein-König *et al.*, 1998) and respiratory tract irritants (Bardana and Montanaro, 1991) such as asthma (Rumchev *et al.*, 2002; Wieslander *et al.*, 1996). There is also a convincing evidence that formaldehyde is an animal carcinogen (Morgan, 1997). William *et al.* (1983) carried out an animal test to examine the carcinogenicity of formaldehyde in rats and mice under long-term exposures. Vaughan *et al.* (1986a, 1986b) exhibits a significant correlation between formaldehyde exposure and *nasopharyngeal.*

Table 2.5: Acute health effects from formaldehyde exposure (Hines *et al.*, 1993)

Formaldehyde concentration (ppm)	**Observed health effects**
<0.05	None reported
0.05-1.5	Neurophysiologic effects
0.05-1.0	Odour threshold limit
0.01-2.0	Irritation of eyes
0.10-25	Irritation of upper airway
5-30	Irritation of lower airway and pulmonary effects
50-100	Pulmonary edema, inflammation, pneumonia
>100	Coma, death

Standard and guidelines: The recommended limit for an 8-hour time–weighted average airborne concentration exposure for formaldehyde is 0.1 ppm (DOSH, 2005; ENV, 1996). The other threshold limits are 0.3 ppm (ACGIH, 2005; MAK, 2000), 0.016 ppm (NIOSH, 2004) and 0.75 ppm (OSHA).

2.2.1.6 Respirable Particles

Exposure sources: In environmental science, particulate matter refers to solid particles or liquid droplets suspended in the air, which is one of the major sources of air pollution. Respirable particles are particulates with an aerodynamic diameter smaller than 10 micron, which are also known as PM_{10}. The composition of the particulate matter is very complex, and is primary dependent on its source. For example, smoke is one of the sources with respirable particles as primary constituents (Cooper, 1980). Smoke from the burning of biomass produces complex mixture of pollutants, both in physical and chemical characteristics, and toxicological properties (Lambert, 1997). The time for respirable particles to reside in the air is very long, which allows these small particles (around 6-7 μm, or less) to accumulate in the lungs (Martonen *et al.*, 1992). This significantly impacts occupants health.

Respirable particulate matter is a mixture of organic and inorganic substances including aromatic hydrocarbon compounds, trace metals, nitrates and sulphates (Maroni *et al.*, 1995). Smoke is the most important source of particulate matter in indoor environments for developing countries, as the burning of biomass is often undertaken without proper ventilation in many buildings (Gold, 1992). This can be supported by a study carried out by Pandey *et al.* (1989) in India, whereby airborne particle concentrations of 21,000 μg m^{-3} are measured during cooking. Similar results were obtained for studies in other developing countries for a typical duration of 24 hours with mean PM_{10} values ranging between 300 - 3000 μg m^{-3} and reached 30,000 μg m^{-3} during cooking (Albalak *et al.*, 1999; Anderson, 1978; Collings *et al.*, 1990;

Ellegard, 1996, 1997; Martin, 1991; McCracken and Smith, 1998). Developed countries replaced the burning of biomass for heating and cooking with natural gas and electricity (Lambert, 1997). Hence, the main source of indoor pollution for respirable particles in developed countries arises from smoking.

Exposure: In the absence of significant indoor sources, indoor to outdoor ratios of respirable particles are generally slightly below unity (Wallace, 1996; Janssen *et al*., 1998). A Harvard study on residential buildings in six cities, covering 470 non-smoking homes, recorded mean annual $PM_{2.5}$ (particles less than 2.5 μm in diameter) concentrations of 17 μg m^{-3} (Neas *et al.*, 1994). A number of houses still used woodstoves for cooking and heating. It was shown that indoor concentrations of respirable particles are slightly above background values (up to 30 μg m^{-3}) during the use of airtight woodstoves and substantially higher with the use of non-airtight stoves (200-1900 μg m^{-3}). When not in operation, homes with wood burning stoves have an average of about 4 μg m^{-3} higher indoor particulate concentrations compared with homes without appliances (Traynor *et al.*, 1986).

Health Effects: Inhalation of respirable particles may lead to airway constriction, such as particles from smoke during the burning of wood, particularly for vulnerable groups such as children and infants. Honickey *et al.* (1985) found that 84% children reported at least one severe symptom, compared to 3% children in homes without wood burning stoves. Similar results were obtained by Dockery *et al.* (1993) which compared wood-burning stoves and other sources of heating in a study comprising of six cities

(Dockery *et al.*, 1993). Infants exposed to wood smoke have a higher probability of access to asthma symptoms (Koeing *et al.*, 1993). Long-term exposure (over 20 years) to high concentrations of indoor particles for non-smokers will result in reduction of lung functions (Abbey *et al.*, 1998). Polycyclic aromatic hydrocarbons (PAH) in wood smoke are a fat-soluble compound resulting from incomplete combustion of wood, which contain organic compounds more than one benzene ring (Maroni *et al.*, 1995). PAH compounds can be easily inhaled into the respiratory system once airborne, which increases the rate of lung cancer (Boffetta *et al.*, 1997). Carcinogenetic properties of PAH are caused by their metabolism within the human body (Sisovic *et al.*, 1996). Mumford *et al.* (1995) discovered that residents with the highest urinary concentration of PAH metabolites in villages will acquire high cancer death rates during a study in China.

Standards and guidelines: The recommended air quality standard for respirable particles less than 10μm is 150 μg m^{-3} based on Malaysia and Singapore guidelines (DOSH, 2005; ENV, 1996). The threshold limits for other internati6onal standards are 10 mg/m^3 (ACGIH, 2005) and 4 mg/m^3 (MAK, 2000).

2.2.2 Biological Pollutants

Discussions on indoor pollutants are commonly focused on chemical contaminants. However, the impact of inhaled biological contaminants on occupants' health should not be underestimated, as there is a huge quantity of biological materials present indoors (Montanaro, 1997).

2.2.2.1 Fungi, Mould and Bacteria

Exposure sources: Microorganism is a microscopic organism that comprises either a single cell or cell clusters (Madigan *et al.*, 2010). Microorganisms are very diverse and they include bacteria, fungi, archaea, protists, microscopic plants and animals. From these microorganisms, various species of fungi and bacteria can be found in organic matter within indoor environments (IEH, 1996). However, the outdoor air penetrating into indoor environment may be a major source of fungi and materials for indoor environments, especially during more humid and warm ambience, such as summer and autumn (Wanner, 1993). Studies showed that building function has an insignificant effect on fungal composition and it is mainly determined by climate (Amend *et al.*, 2010). This indicates that high humidity levels favour the growth of fungi and mould (Nielsen *et al.*, 2004; Sterling and Lewis, 1998).

Exposure: In UK, a study which covers 163 homes during a period of 26 months revealed a geometric mean count of 234 colony forming unit (CFU) m^{-3} in air for fungi, and 365.6 CFU m^{-3} air for bacteria. It was observed that *Penicillium* is the most frequently isolated fungus, found in 53% of samples, whereas the dominant bacterium is *bacillus (*Hunter *et al.*, 1996*)*. Similar findings were obtained in Norway, whereby a study was carried out on homes and schools. *Penicilium* was determined to be the most common micro-fungus (Dotterud *et al.*, 1995). In Japan, fungal concentrations for indoor environments were recorded within a range of 13 - 3750 CFU m^{-3} at Yokohama (Takahashi, 1997). In Singapore, Cheong and Chong (2001) reported an evaluation of microbial pollutants for air-conditioned office with samples of air for occupant level,

with a range of 79-334 CFU m^{-3} and 70-132 CFU m^{-3} for bacteria and fungi respectively. A study at an apartment in USA measured a reading of 198 CFU m^{-3} for spore concentrations (Macher *et al.*, 1991).

Health effects: Exposure to airborne bacteria and fungi will increase the risk of acquiring a number of well-defined diseases (Peat *et al.*, 1998). Table 2.6 shows a summary of several reported diseases and syndromes associated with respective fungi and bacteria. One of the major symptoms are related to human respiratory and breathing systems, such as allergies and asthma. This is supported by the findings of Platt *et al.* (1989) and Potter *et al.* (1991) in the UK, which determined between the relationship between fungal spores and allergic respiratory and breathing symptoms. Studies carried out by Wickman et al. (1992) in Sweden and Neas *et al.* (1996) in US identified some common allergens for children, such as *Penicillium*, *Alternaria* and *Cladosporium*. Recent studies revealed that respiratory symptoms may not be due to exposure to spores (Howden-Chapman *et al.*, 1996). Rather, they are attributed to the mycotoxins emitted by fungi and readily absorbed through the membranes (Hendry and Cole, 1993). *Legionnaire's* disease is one of the well-known diseases caused by bacteria, which was first identified in Philadelphia in 1976 (Fraser *et al.*, 1977). The disease causes malaise and headaches, followed by dry cough, chest pain, diarrhoea, and altered mental status (Ayars, 1997).

Table 2.6: Diseases and disease syndromes associated with exposure to bacteria and fungi (IEH, 1996)

Disease/Syndrome	Examples of Casual Organisms Cited
Rhinitis (and other upper respiratory symptoms)	*Alternaria, Cladosporium, Epicoccum*
Asthma	Various aspergilla and penicillia, *Alternaria, Cladosporium, Mucor, Stachybotrys, Serpula*
Humidifier fever	Gram-negative bacteria and their lipopolysaccharide endotoxins, Actinomycetus and fungi
Extrinsic allergic alveolitis	*Cladosporium, Sporobolomyces, Aureonasidium, Acremonium, Rhodotorula, Trichosporon, Serpula, Penicillium, Bacillus*
Atopic dermatitis	*Alternaris, Aspergillus, Cladosporium*

Standards and guidelines: There are currently no specific international standards for microbial contaminants. The only guideline available is the Singapore guidelines for indoor air quality of office buildings with a threshold limit of 500 CFU m^{-3} for bacteria and fungi. British Health Technical Memorandum (HTM) 2025 is a comprehensive and influential standard for operating rooms, which suggests a threshold limit for airborne counts of 180 CFU m^{-3} for working theatres, and 35 CFU m^{-3} for operating rooms without occupants. For operating rooms, sampling should be taken after the ventilation system runs for an hour following the closure of all doors and leaving the operating room empty by remote or automatic start-up. A general requirement is that the air-handling unit (AHU) for operating rooms is operated at normal flow rates continuously for at least 24 hours prior to sampling (HTM2025, 1994a; MOH, 2010).

2.3 Sick Building Syndrome

Comparison: Sick Building Syndrome (SBS) is a combination of ailments associated with an individual's workplace. Another building related health problem is Building Related Illness (BRI), which must be distinguished from SBS. BRI involves the spread of infectious diseases within a building ventilation service, such as legionnaire's disease, whereas SBS comprises a group of symptoms after the occupants reside in the building, whereas such symptoms will improve within a few hours upon leaving the building (Burge, 2004). This gives a small difference although the term "building" is used for both health problems. BRI is related to the ability of a building ventilation system's response when encountered with an outbreak of infectious diseases, and the management of indoor air pollutants such as chemicals used within the building. In contrast, SBS represents some general symptoms faced by occupants in a particular building, which is called "sick building".

Health Effects: Health problems associated with indoor environments become a common health challenge for medical doctors (Burge, 2004; Finnegan *et al.*, 1984; Frank, 1986; Kelland, 1992). Table 2.7 displays a number of the most common symptoms for SBS. SBS symptoms can be classified into a few categories, such as mucous-membrane irritations, neurotoxic effects, respiratory symptoms, skin symptoms and chemosensory changes (Redlich *et al.*, 1997). Several general symptoms such as tiredness and headaches are adopted usually by occupants in a sick building, which initiate within a few hours of being inside the building, and the symptoms improve when leaving the building (Burge, 2004).

Table 2.7: Common symptoms of sick building syndrome (Wallace, 1997)

Common Symptoms
Headache and nausea
Nasal congestion (runny/stuffy nose, sinus congestion, sneezing)
Chest congestion (wheezing, shortness of breath, chest tightness)
Eye problems (dry, itching, tearing, or sore eyes, blurry version, burning eyes, problems with contact lenses.
Throat problems (sore throat, hearseness, dry throat)
Fatigue (unusual tiredness, sleepiness, or drowsiness)
Chills and fever
Muscle pain (aching muscles or joints, pain or stiffness in upper back, pain or stiffness in lower back, pain or numbness in shoulder/neck, pain or numbness in hand or wrists)
Neurological symptoms (difficulties remembering or concentrating, feeling depressed, tensed, or nervousness)
Dizziness
Dry skin

Sources: Volatile organic compounds were once believed to be the major cause of SBS, based on experimental chamber studies whereby people exposed to a mixture of VOC encountered similar symptoms as that for SBS (Mølhave *et al.*, 1986). This suggestion was further supported by a longitudinal study by Berglund *et al.* (1990) in a "sick" library building, and Hodgson *et al.* (1991) for office workers. However, Sundell *et al.* (1993) showed that VOC are not the major cause of SBS, and that VOC are simply one of the contributors of SBS.

Another factor that plays an important role in SBS is building ventilation systems (Bourbeau *et al.*, 1997; Hodgson *et al.*, 1994; Mendell, 1993). Studies showed a reduction in SBS symptoms for indoor occupants with increasing outdoor to indoor air ratio (Nagda *et al.*, 1996; Sundell *et al.*, 1993). However, Mendell (1994) showed a conflicting result in determining the role of building ventilation on SBS. It was found

that air-conditioning mechanical ventilation systems are not necessarily better than naturally ventilated systems. A study on the relationship between symptoms reported by office workers and ventilation provision showed that workers in air-conditioned offices reported higher SBS symptoms such as work-related headaches, lethargy and upper respiratory symptoms compared with naturally ventilated buildings (Mendell and Smith, 1990). Similar findings were observed by Harrison *et al.* (1987), which compared eight naturally ventilated and 19 mechanical ventilated buildings.

The mental state of respondents influences stimulus-response, which greatly affects their sensory irritation towards occupied office environments (Dalton, 1996). Dalton *et al.* (1997) examined this by exposing different groups of individuals to acetone. They were given different information about the consequence of long-term exposure to acetone. The results showed that less odour and irritation were reported by respondents with positive information.

Multiple chemical sensitivity (MCS) is believed to be a syndrome affecting SBS. Inhabitants exposed to mixtures of chemically distinct substances at very low doses will experience these symptoms (Nethercott, 1996). The concept of MCS was developed since the 1960 resulting from food allergy concerns (Shorter, 1997). A recent study revealed that the amount of people suffering from MCS increased. For example, one-third of US citizens suffered from MCS (Meggs *et al.*, 1996). MCS is a well-explained SBS reported in buildings with low pollutant concentrations. However, studies were unable to identify the clinical mechanisms related to MCS (Wolf, 1996),

whereby MCS patients are more likely to display symptoms of depression and anxiety (Simon *et al.*, 1993). Hence, it is a argued that MCS has a stronger influence psychologically rather than on a clinical basis (Shorter, 1997).

There were studies on psychosocial factors associated with several common SBS symptoms. Occupational stress during workplace such as work overload, role ambiguity and low status will influence the health of office workers (Kivimaki, 1996). This is supported by the study of Erikssonm and Höög (1993) in Sweden. Generally, SBS is influenced by multiple factors, consisting of chemical, biological, physical and psychological. Table 2.8 shows some common factors of SBS.

Table 2.8: Common factors of SBS (Redlich *et al.*, 1997)

Factor	**Sources**
Volatile organic compounds	Formaldehyde, solvents, printer and photocopier emissions, paint and resins, printed materials
Dust / Fibre	Asbestos, man-made mineral fibres (fiberglass), dirt, construction and paper dust
Bio-aerosols	Bacteria, moulds, viruses, pollen, fungi, dust mites, animal danders and excreta
Entrapped outdoor sources	Vehicle exhaust, industrial exhaust
Physical factors	Temperature, noise, humidity, lighting
Contaminants generated by human activity	Carbon dioxide, perfume
Others	Fuel combustion products, radon, environmental tobacco smoke, cleaning agents, pesticides, building materials

2.4 Thermal Comfort

Definition: Human thermal comfort has been defined as "the condition of mind that expresses satisfaction with the thermal environment" by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) (ASHRAE, 2004). This statement explains the meaning of "condition of mind" or "satisfaction", as the process of determining comfort is cognitive which involves various factors such as psychological, physical and physiological factors (Lin and Deng, 2008). The human mind will sense temperature and moisture through sensation from the skin, as well as the internal body temperature to decide whether the current environment is comfortable or uncomfortable. The human mind also decides the necessity to regulate body temperature by dissipating heat generated by human metabolism in order to maintain heat balance with the surrounding environment (Berglund, 1995; Gagge, 1937). This shows that the feeling of "cold" or "hot" is not dependent solely upon the air temperature, and comfort is not a state condition, but rather a state of mind.

Governing factors: Thermal sensation for different individuals will vary even in the same environment. The opinions on thermal comfort are attributed to a combination of a large number of factors affecting the perception of human beings (Djongyang *et al.*, 2010). Although climates, living conditions, and culture differ widely throughout the world, the temperature in which people choose for thermal comfort under similar conditions is found to be very similar after considering the factors influencing thermal sensation (Busch, 1992; Fanger, 1972). Macpherson (1962) defined six factors affecting thermal sensation: two personal variables (clothing insulation and activity level), and

four physical variables (air temperature, air velocity, relative humidity, mean radiant temperature).

Impact: There is evidence that thermal comfort affects on occupants' health and productivity within the workplace (Griffiths and Boyce, 1971; Taylor *et al.*, 2008; Wagner *et al.*, 2007). Thus, thermal comfort standards and guidelines are established to ensure the health and well-being of occupants. These standards and guidelines play a vital role in determining energy consumption by the ventilation system, which is associated with the building's sustainability (Yao *et al.*, 2009). Increased energy use implies that there will be more combustion of fossil fuels, which contributes to carbon dioxide emissions and climate changes (Kwok and Rajkovich, 2010).

2.4.1 Conditions for Thermal Comfort

The "Thermal Environmental Conditions for Human Occupancy" standard provides the conditions required for an acceptable thermal environment. This standard specifies conditions or comfort zones where 80% of sedentary or slightly active persons are found to be thermally satisfied. Summer and winter comfort zones are specified with clothing insulation levels of 0.5 *clo* and 0.9 *clo* (0.078 m^2.K/W and 0.14 m^2.K/W), respectively. In Figure 2.1, the summer comfort zone is highlighted since the weather condition in tropical areas approximates the summer condition in seasonal countries. The warmer and cooler temperature borders of comfort zones are affected by humidity, and they coincide with lines of constant ET*. The effective temperature (ET*) is the temperature at 50% RH that yields the same total heat loss from the skin as for the

actual environment (ASHRAE, 2004).

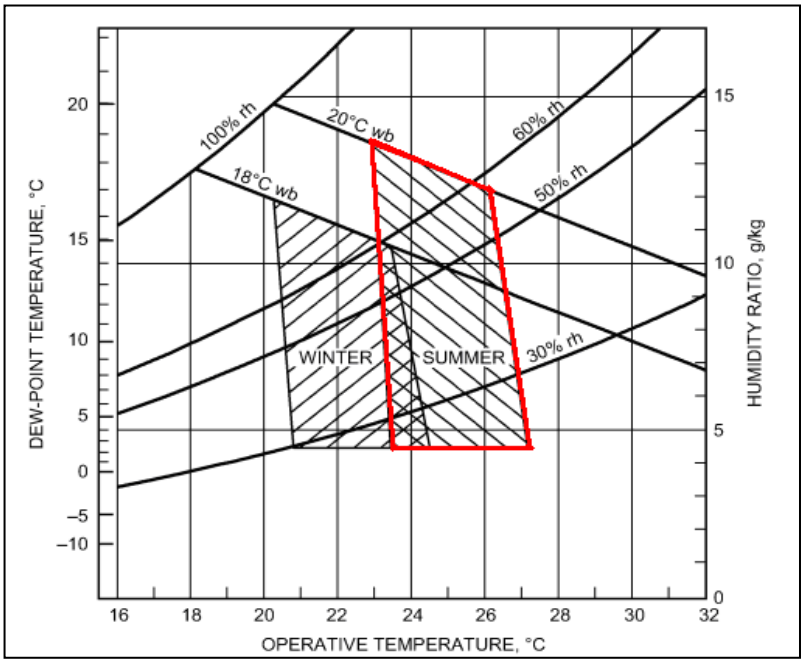


Figure 2.1: ASHRAE Summer Comfort Zone
(Acceptable ranges of operative temperature and humidity for people in typical summer clothing during primarily sedentary activity.) (ASHRAE, 2004)

In the region where winter and summer zones overlap, people in summer dress tend to approach a slightly cooler sensation. However, those in winter clothing would approach a slightly warmer sensation. The comfort zones for other clothing levels can be approximated by decreasing the temperature borders of the zones by 0.6 K for an 0.1 *clo* increase in clothing insulation and vice versa. Similarly, a zone's temperature can be decreased by 1.4 K per *met* increase in activity above 1.2 *met*. The ASHRAE Standard 55 recommends that the dew point temperature of occupied spaces should not be less than 23 ℃ and the relative humidity of the warm side of the comfort zone not exceed 60% (ASHRAE, 2004). The thermal condirions specified by the ASHRAE standard-55 are summarized in Figure 2.2, for summer and winter seasons.

Season	Optimum Temperature	Acceptable Temperature Range	Conditions
Winter	22°C	20-23°C	Relative humidity: 50% Mean air velocity : <0.15m/s MRT = T_a Metabolic rate: 1.2 met Clothing insulation: 0.9 clo
Summer	24.5°C	23-26°C	Relative humidity: 50% Mean air velocity : <0.15m/s MRT = T_a Metabolic rate: 1.2 met Clothing insulation: 0.9 clo

Figure 2.2: Thermal comfort conditions (ASHRAE, 2004)

According to Malaysian Standard MS 1525-2001, entitled "Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-residential Buildings" (MS1525, 2007), the acceptable indoor conditions for the design and maintenance of thermal comfort are as follows:

Recommended dry bulb temperature = 23 - 26 ℃

Recommended relative humidity = 55 - 70%

Recommended air movement = 0.15 to 0.5 m/s

Individual thermal sensation is an objective sensation, which can be evaluated by the subject's diagnosis in order to determine an overall evaluation of the thermal comfort provided by the building's ventilation system (Kuchen and Fisch, 2009). The ASHRAE seven-point thermal sensation scale is developed to quantify the average thermal sensation felt by a participant (ASHRAE, 2004). Nicol *et al.* (1994) modified the ASHRAE seven-point scale in order to predict thermal temperature using equation (2.4) and (2.5). The seven-point thermal sensation scales are shown in the Table 2.9.

Table 2.9: Mean Thermal Sensation Scales

Comfort Vote	(ASHRAE, 2004)	(Nicol *et al.*, 1994)
Hot	+3	7
Warm	+2	6
Slightly warm	+1	5
Neutral	0	4
Slightly cool	-1	3
Cool	-2	2
Cold	-3	1

$$\text{Mean Thermal Sensation}, C_m = \frac{\sum_{i=Cold}^{Hot}[\text{No. of Vote for sensation i} \times \text{sensation i index}]}{Total\ Vote} \quad \text{---- (2.4)}$$

$$Comfort\ temperature, T_C = T_{gm} + \frac{4-C_m}{a*} \quad \text{----------(2.5)}$$

Where, a^* = Slope or regression coefficient

C_m = Mean comfort vote

T_{gm} = Mean Internal temperature

There are several studies with different regression coefficients reported as shown in Table 2.10. However, Nicol *et al.* (1994) and Humphreys (1976) showed that regression analysis is liable to errors due to feedback. Hence, a regression coefficient of 0.33 from Fanger (1970) is chosen.

Table 2.10: Slope or Regression coefficient

Study	Regression Coefficient
(Fanger, 1970)	0.33
(Nicol *et al.*, 1995)	0.25
(Humphrey, 1976)	0.23
(Sharples and Malama, 1997)	0.21

2.5 Hospital Indoor Conditions

The indoor conditions for healthcare facilities, such as patient wards, surgical wards and isolation rooms play a more crucial role rather than merely providing comfort unlike other HVAC buildings. Controlled environment is necessary for different conditions such as operations, for patients who could not tolerate hot and humid conditions (e.g. thyrotoxicosis), as well as cardiac patients to ensure normal heat loss (ASHRAE, 2007b). Hence, temperature and humidity are governing factors for patient recovery. Studies indicates that air quality and infection rates are closely related to the direction of airflow and air pressure, humidity, temperature, air changes per hour in the room, type of air filter, and ventilation system cleaning and maintenance (Lutz *et al.*, 2003; McDonald *et al.*, 1998) These factors will be discussed further in the subsequent sections.

2.5.1 Humidity and Temperature

Humidity: Humidity is an expression used to describe water vapour in the air, and it is more commonly used in terms of relative humidity, which is expressed in percentage. Humidity is an important control parameter to be considered for ACMV operations, especially in hospitals. Low humidity levels favor blood coagulation and will generate problems associated with static electricity (Balaras *et al.*, 2007). Human thermal comfort is influenced by humidity as human body uses evaporative cooling to regulate body temperature. As humidity is high, the rate of heat transfer is lower, which results in the respondent feeling warmer compared with lower humidity at a given temperature. This is supported by Yu *et al.* (2003), who studied the thermal comfort in

tropical climates. Humid environment favours the growth of indoor microbial pollutants (Nielsen *et al.*, 2004), which should be avoided especially for surgical sites in healthcare facilities to prevent surgical site infection (SSI). Certain medical treatments involve the control of temperature and relative humidity in the healing process, especially for heat-related illnesses (Wexler, 2002).

Temperature: There are two types of air temperature measurements, namely, dry-bulb and wet-bulb temperature. The dry-bulb temperature is also commonly assumed as the air temperature. Unlike dry-bulb temperature, wet-bulb temperature accounts for the amount of moisture in the air. Besides humidity, the design temperature for indoor air is also an important factor which determines the comfort level of occupants (ASHRAE, 2004). It has been suggested that temperature may bring health impacts to patients in addition to heat-related illnesses. For example, Schwartz *et al.* (2004) showed that heart disease admissions increase as temperature increases for a study covering 12 cities in the US. Similar to humidity, temperature has an influence on microbial pollutants in indoor environments such as fungal growth (Nielsen *et al.*, 2004).

For environment control in buildings using HVAC systems, the maintenance of temperature and relative humidity within a suitable and comfortable range is important. The key issue is to maintain a comfortable environment to avoid problems associated with extremely dry or extremely humid air, such as dry skin for occupants, paint covers on the surface of wooden furniture which will fracture due to shrinkage, and static

electricity. Extremely humid air will lead to problems with mould, corrosion, decay and other moisture-related deterioration.

In general, temperature and humidity control are governing factors in occupant thermal comfort, medical appliance conditions (electric static), infection control, as well as medical treatments. The normal temperature and humidity for inpatient areas in healthcare facilities should be less than 24 ℃, with relative humidity ranging between 30-60% (ASHRAE, 2007b).

2.5.2 Ventilation and Pressure Relationship

Many researches indicated that ventilation has a great impact on the building IAQ (Batterman and Burge, 1995; Seppanen and Fisk, 2004; Wu *et al.*, 2005). Poor ventilation is found to be related to asthma, mucosal irritation, dry or irritated throat, dizziness, headache, irritated or itchy eyes, hoarseness or pain in throat, irritated stuffy nose and runny nose (Morey and Shattuck, 1989). Ventilation is believed to be the governing factor for SBS (Redlich *et al.*, 1997), as well as risks associated with airborne transmission (Li *et al.*, 2007).

Although there are various international ventilation guidelines for healthcare facilities, most of these guidelines focus on specialist facilities, such as isolation rooms and operating rooms, whereby the risks associated with airborne infection are well studied. Information on ventilation for general ward space is presently very sparse in nature, and is often vague. For example, the UK guideline (HTM 2025) rarely mentions

facts regarding the ventilation of clinical spaces other than operating rooms (HTM2025, 1994a). General ward ventilation systems are designated to provide patient comfort and reduce energy costs, rather than clinical reasons. It was once assumed ward ventilation has little impact on hospital infection, and thereby, there are no strict rules for normal wards. Recent studies revealed that ventilation may play a vital role in spreading infection within wards (Bernards *et al.*, 1998; Shiomori *et al.*, 2001; Shiomori *et al.*, 2002). This indicates that the potential of infection has been underestimated, and is necessary to re-evaluate on the basis of current healthcare ventilation systems.

The minimum air change in outdoor air per hour is between 2 to 4 air changes per hour (ACH) for most surgery and critical areas, with provision of positive pressure compared with adjacent rooms. The aim of ventilation design for healthcare facilities is to ensure the movement of air from clean to less clean areas by creating different pressures for each serving zone. This design concept is also applicable for infectious isolation units. There are numerous studies which indicate a relationship between ventilation of buildings and airborne infections (Li *et al.*, 2007; Tang *et al.*, 2006). The pressure relationship between different interior spaces is required to mitigate the transmission of airborne infectious diseases. Adequate ventilation will reduce the risk of airborne infections (Nardell *et al.*, 1991), as the concentration of airborne contaminants decreases with increasing dilution effect (Chow and Yang, 2004).

2.5.3 Air Filter

Impact: A number of studies showed that high air cleanliness can reduce the rate of infection for high-acuity patient groups; for example, HEPA-filtered isolation rooms (Passweg *et al.*, 1998; Sherertz *et al.*, 1987; Sherertz and Sullivan, 1985). Air contaminants are minimal with the use of HEPA filters with laminar airflow, which are recommended for critical areas such as isolation rooms, operating rooms, and intensive care units (Dharan and Pittet, 2002; Friberg *et al.*, 2003; Hahn *et al.*, 2002; Sherertz *et al.*, 1987). Therefore, CDC and HICPAC recommended HEPA filters for healthcare facilities, either required or strongly recommended for implementation in all areas (Sehulster and Chinn, 2003). Proper selection of air filtration is important to obtain good performance and cost management for ventilation systems.

Standards: Table 2.11 shows the minimum filter efficiency values (MERV) of filters recommended by ASHRAE Standard 52.2, and in percentages determined by ASHRAE Standard 52.1 (ASHRAE, 1992, 2007c) for general hospitals, according to their designated areas. Several areas consists of one filter bed (Filter bed no. 1), which should be installed upstream of the ventilation equipment. The second filter bed should be located downstream of the supply fan (ASHRAE, 2007b). There are several cases in which high efficiency filters are required, such as operating and isolation rooms. High-efficiency particulate air (HEPA) and ultra-low penetration air (ULPA) filters are commonly used to attain a protective environement.

Table 2.11: Filter efficiencies for central ventilation and air-conditioning systems in general hospitals (ASHRAE, 2007b)

Minimum Number of Filter Beds	Area Designation	Filter Efficiencies, MERV (%)	
		Filter Bed	
		No.1	No.2
2	Orthopaedic operating room Bone marrow transplant operating room Organ transplant operating room	8 (30%)	17[a] (99.97%)
2	General procedure operating room Delivery room Nurseries Intensive care units Patient care rooms Treatment rooms Diagnostic and related areas	8 (30%)	14 (90%)
1	Laboratories Sterile storage	13 (80%)	
1	Food preparation areas Laundries Administrative areas Bulk storage Soiled holding areas	8 (30%)	

[a]HEPA filters at air outlets

Installation: Proper installation is required to enable an effective performance of air filters. Leakage between filter segment, filter bed and its supporting frame should be avoided. This supported by a study carried out by Ward and Siegel (2005), which showed that a small gap of 10 mm reduces filter efficiency from MERV 15 to MERV 8. Small gaps lead to leaks, which permit contaminated air to pass through the air filter and enter the controlled environment, which will pollute the indoor air and decrease its cleanliness.

Pre-filter: A number of filters are installed before the air reaches the high efficiency filters. Such filters are known as pre-filtration or pre-filters. Pre-filters are used to capture larger air particles, with the purpose to extend the life of the

high-efficiency filters and conserve their reliability to capture smaller particles. Table 2.12 provides more detailed information on air filters or cleaner types based on controlled contaminants and typical applications.

Table 2.12: Comparison between ASHRAE Standards 52.1 and 52.2 (ASHRAE, 1992, 2007c)

Std. 52.2 MERV	**Approx. Std. 52.1**		**Application Guidelines**		
	Dust Spot Efficiency	**Arrest -ance**	**Typical Air Filter /Cleaner Type**	**Typical Controlled Contaminant**	**Typical Applications**
20	n/a	n/a	**HEPA/ULPA Filters:** >99.999% efficiency on 0.10-0.20 ìm particles IEST Type F	**<0.30 ìm Particle Size** Virus (unattached) Carbon dust Sea salt All combustion smoke Radon progeny	Cleanrooms Radioactive materials Pharmaceutical mfg. Carcinogenic materials Orthopedic surgery
19	n/a	n/a	>99.999% efficiency on 0.30 ìm particles IEST Type D		
18	n/a	n/a	>99.99% efficiency on 0.30 ìm particles IEST Type C		
17	n/a	n/a	>99.97% efficiency on 0.30 ìm particles IEST Type A		
16	n/a	n/a	**Bag Filters** Non-supported (flexible) microfine fiberglass or synthetic media. 300 to 900 mm (12 to 36 inch) deep, 6 to 12 pockets. **Box Filters** Rigid style cartridge filters 150 to 300 mm (6 to 12 inch) deep may use lofted (air laid) or paper (wet laid) media.	**0.30-1.0 ìm Particle Size** All bacteria Tobacco smoke Droplet nuclei Insecticide dust Copier toner Most face powder Most paint pigments	Hospital inpatient care General surgery Smoking lounges Superior commerical buildings
15	>95%	n/a			
14	90-95%	>98%			
13	80-90%	>98%			
12	70-75%	>95%	**Bag Filters** Non-supported (flexible) microfine fiberglass or synthetic media. 300 to 900 mm (12 to 36 inch) deep, 6 to 12 pockets. **Box Filters** Rigid style cartridge filters 150 to 300 mm (6 to 12 inch) deep may use lofted (air laid) or paper (wet laid) media.	**1.0-3.0 ìm Particle Size** Legionella Humidifier dust Lead dust Milled flour Coal dust Auto emissions Nebulizer drops Welding fumes	Residential Better commerical buildings Hospital laboratories
11	60-65%	>95%			
10	50-55%	>95%			
9	40-45%	>90%			

2.5.4 Healthcare Facility Design Guidelines

There are no specific design guidelines for healthcare facilities in tropical climates such as Malaysia. Therefore, international guidelines and standards are examined to understand the common desirable design parameters. Table 2.13 shows the design parameters presented by ASHRAE in the US. There are five parameters which need to be considered, namely, air pressure relationship to adjacent area, minimum air changes of outdoor air, minimum total air change rate, relative humidity, and design temperature. The ASHRAE Standard 170 recommends 24℃ as the threshold limit for indoor air temperature, with a relative humidity of 30-60 %. The relative humidity should be set at a higher percentage for patient wound recovery and in wound intensive care wards (40-60% RH).

Table 2.13: Design parameters from ASHRAE Standard 170-2008 (ASHRAE, 2008)

Function of space	Pressure relationship to adjacent areas	Minimum air changes of outdoor air per hour	Minimum total air changes per hour	Relative humidity (%)	Design temperature (℃)
Class B and C Operating room	Positive	4	20	30-60	20-24
Operating/surgical	Positive	4	20	30-60	20-24
Cystoscopic rooms					
Delivery room	Positive	4	20	30-60	20-24
Substerile service area	N/R	2	6	N/R	N/R
Recovery room	N/R	2	6	30-60	21-24
Critical and intensive care	Positive	2	6	30-60	21-24
Wound intensive care	Positive	2	6	40-60	21-24
Newborn intensive care	Positive	2	6	30-60	21-24
Treatment room	N/R	2	6	30-60	21-24
Trauma room	Positive	3	15	30-60	21-24
Medical/Anesthesia gas storage	Negative	N/R	8	N/R	N/R
Laser eye room	Positive	3	15	30-60	21-24
ER waiting room	Negative	2	12	Max. 65	21-24

The American Institute of Architects publishes another guideline used in the US (AIA, 2006). For UK, the guidelines consist of CIBSE Guides and Health Technical Memorandum (CIBSE, 2004; HTM2025, 1994a). Table 2.14 shows a comparison between these five international guidelines and standards.

Table 2.14: Comparison between Hospital Design Guidelines

Source	**Pressure relationship to adjacent room**	**Minimum air changes of outdoor air per hour**	**Minimum total air changes per hour**	**Relative humidity (%)**	**Design temperature (℃)**
Patient room					
ASHRAE Handbook (ASHRAE, 2007b)	Neutral	2	6	30-60	24±1
ASHRAE Standard 170 (ASHRAE, 2008)	NULL	2	4	30-60	20-24
AIA Guidelines (AIA, 2006)	NULL	2	6	NUL	21-24
CIBSE Guide B (CIBSE, 2004)	NULL	NULL	6	40-70	NULL
HTM 2025 Guideline (HTM2025, 1994a)	Neutral	NULL	NULL	40-60	20-22
Intensive Care Rooms					
ASHRAE Handbook (ASHRAE, 2007b)	Positive	2	6	30-60	21-24
ASHRAE Standard 170 (ASHRAE, 2008)	Positive	2	6	30-60 40-60	21-24
AIA Guidelines (AIA, 2006)	NULL	2	6	30-60	21-24
CIBSE Guide B (CIBSE, 2004)	NULL	NULL	NULL	NULL	NULL
HTM 2025 Guideline (HTM2025, 1994a)	Neutral	NULL	NULL	30-60	NULL

2.6 Cleanroom

Cleanroom is a controlled environment with low levels of indoor contaminants such as dust, aerosol particles, airborne microbes and chemical vapours. The outdoor air entering a cleanroom is filtered to exclude environmental contaminates to acceptable levels in order to achieve clean space. HEPA and ULPA filters are commonly employed to maintain a suitable environment for cleanrooms.

There is strong evidence that renovation and construction in existing healthcare facilities can increase the risk of nosocomial infections and airborne transmissions (Carter and Barr, 1997; Krasinski *et al.*, 1985; Loo *et al.*, 1996; Mahieu *et al.*, 2000; Opal *et al.*, 1986; Oren *et al.*, 2001). Therefore, the concern for air quality control should begin at the design stage. There are three particulate contaminant sources which should be considered when designing a cleanroom, namely, infiltration air, supply air and internal generation (Zhang, 2004).

2.6.1 Standards Governing Air Cleanliness

There are several international standards used to classify cleanrooms according to the amount of particles contained in a cubic meter of air and different particulate sizes. Three international standards for cleanrooms are compared in table 2.15, namely, GMP guideline for Europe countries, ISO14644-1 and FS209 in the US (Whyte, 2010).

The Institute of Environmental Sciences and Technology (IEST) first published the United States Federal Standard 209 (FS209) in 1963. The last revision of FS209 was

completed in year 1992, resulting in version E (FS 209E). FS 209E was widely used as a cleanroom standard until the advent of the ISO cleanroom standard, resulting from the activities of the ISO Technical Committee ISO/TC209 "Cleanrooms and other associated control environments" which began in 1993. Since November 1999, cleanroom standard ISO 14644-1 became mandatory in the Europe Union (EU). However, the FS 209E Standard is still widely used in Malaysia, along with international cleanroom standard ISO 14644-1.

According to the ISO Classification Air Cleanliness (ISO14644-1, 1999), there are nine class levels for airborne particulate cleanliness, as presented in Table 2.15. These class levels are differentiated by the maximum allowable number of particles per cubic meter of air. For example, an operating room should comply with at least ISO 14644-1 Class 7 or Class 8. Rooms for drug chemical testing are assumed to have similar air cleanliness as operating rooms, which will be elaborated further in Chapter 4.

Table 2.15: Comparison of airborne particle concentration limits from FS 209, ISO14644-1 and EU GMP (GMP, 1997; ISO14644-1, 1999)

GMP Class	FS209 Class	ISO Class	0.1 μ m		0.5 μ m		5.0 μ m	
			Federal Standard 209	ISO	Federal Standard 209	ISO	Federal Standard 209	ISO
			Particles/m^3					
		1		10				
		2		100		4		
	1	3	1230	1000	35	35		
	10	4	12200	10000	353	352		
A/B	100	5	122000	100000	3530	3520		29
	1000	6	1220000	1000000	35300	35200	247	293
C	10,000	7	1.22×10^7		353000	352000	2300	2930
D	100,000	8	1.22×10^8		3530000	3520000	24700	29300
		9	1.22×10^9			35200000		293000

The classification above is based on the following equation (ISO14644-1, 1999),

$$C_N = 10^N \left[\frac{0.1}{D}\right]^{2.08} \quad \text{---------- (2.6)}$$

where

C_N = maximum allowable particle concentration, in (particles/m^3),

N= ISO classification number, from 1 to 9,

D= particle size inμm.

In addition to these three international standards, some countries have their own national version of cleanroom guidelines, with minor changes of the classes to comply with the metric system. A number of examples include France (AFNORX44101), Australia (AS 1386), China (GBJ73-84), Germany (VDI 2083), Russia (Gost-R50766), Japan (JIS-B-9920 and United Kingdom (BS 5295). Table 2.16 shows a comparison between cleanroom standards for different countries.

Table 2.16: Comparison between cleanroom standards for different countries (Whyte, 2010)

Country	**Year**	**Standard**	**Classification**					
Australia	1989	AS 1386	0.035	0.35	3.5	35	350	3,500
France	1972	AFNORX 44101	-	-	4,000	-	400,000	4,000,000
UK	1989	BS 5295	C	D	E/F	G/H	J	K
Europe	1997	EU GMP	-	-	A/B	-	C	D
US	1992	FS 209E	M1.5	M2.5	M3.5	M4.5	M5.5	M6.5
China	1984	GBJ73-84	-	-	100	1,000	10,000	100,000
Russia	1995	Gost-R 50766	P3	P4	P5	P6	P7	P8
Japan	1989	JIS-B-9920	3	4	5	6	7	8
Germany	1990	VDI 2083	1	2	3	4	5	6
International	1993	ISO 14644-1	3	4	5	6	7	8

2.7 Engineering Control

Control is implemented to reduce occupants' exposure to contaminants in order to achieve a healthy living environment. Control can be divided into two categories, consisting of engineering control (i.e. source control, filtration, dilution, antimicrobial), and administrative control (personal protective equipment, workers' education, scheduling) (Ellenbecker, 1996).

Source of pollutants for indoor air exist in both internal and external environment. Indoor air quality can be controlled by removal of contaminants or dilution (Stoecker and Jones, 1982). Studies showed that combined air filtration and dilution ventilation are able to reduce particle concentrations, typically from 30% to 90%. The air filters used in the study are not merely HEPA filters; rather the filters are coupled with engineering control, in which the filter media perform as effectively as filters containing HEPA media (Miller-Leiden *et al.*, 1996).

Filtration: Filtration is one of the most common engineering control strategies for indoor air quality, especially in healthcare facilities. Filtration is a mechanical or physical operation, which is employed for separation of small particulates from air, such as dust, mould, pollen and bacteria. (See Section 2.5.3 for more details).

Dilution: Dilution with ventilation air is another economically and technically preferred engineering control. This engineering control is usually applied in buildings in which major sources are under control and no special measures are required (ASHRAE,

2009b). Ventilation air is made up of circulated air and outdoor air, whereby outdoor air is used for dilution. Dilution refers to reducing the concentration of indoor air contaminants with the introduction of "clean air" (Stoecker and Jones, 1982).

Source control: The most effective way to improve indoor air quality is to eliminate individual sources of pollution or to reduce their emissions. Studies of Levin (1989, 1991) emphasized on source control in designing good IAQ buildings. Careful selection of building materials is effective in controlling building IAQ. For example, materials containing asbestos can be sealed or enclosed. Administrative control is a type of source control, whereby the use of volatile organic compounds, housekeeping activities, and pesticide applications can be scheduled at low occupant density hours. Possible indoor sources are prudent to be isolates and should be eliminated by local exhaust ventilation in order to prevent such sources from becoming a problem (ASHRAE, 2009b). Source control is more cost-efficient compared to other control strategies, as increasing ventilation results in incurring energy costs.

Control of biological pollutants is a more complex issue. Unlike other contaminants which originate from indoor or outdoor sources, microbial pollutants behave as source of pollution as they can grow in indoor environments (Flannigan and Miller, 2011). Therefore, the control of biological pollutants will be divided into two parts, namely, 1) removal and collection of bioaerosols, and 2) elimination or deactivation of all forms of microbiological life (ASHRAE, 2009b; Rutala and Weber, 1999a).

Filters: The maximum removal of airborne microorganisms is either necessary or required for microbial pollutants. Thus, high-efficiency particulate (HEPA) or ultralow penetration air (ULPA) filters are used to create an indoor environment with very low particulate levels. However, the total control of airborne microorganisms is not required for many situations. There are various types of filters with different applications which can be used to provide necessary efficiency for such conditions, such as dry-media and extended-surface filters (ASHRAE, 2009b).

Ultraviolet radiation: One of the engineering controls used for control of airborne microorganisms in healthcare facilities is the use of ultraviolet (UV) radiation (ASHRAE, 2009b). Mechanical ventilated air passing through the UV lamps will be sterilized to prevent cross-infection. This method is known as ultraviolet germicidal irradiation (UVGI), whereby short wavelengths are used to reduce the concentrations of active microorganisms. Green and Scarpino (2002) showed that UVGI can effectively kill 99% of all airborne vegetative bacteria tested, such as *E. Coli* (99.973%), *S. aureus* (99.968%), and *M. luteus* (99.260%). Studies from other researches support the implementation of UVGI in airborne microorganism control (Green and Scarpino, 2002; Kujundzic *et al.*, 2006; Macher *et al.*, 1992; Miller and MacHer, 2000; Xu *et al.*, 2003).

Biocides or antimicrobials: Chemicals are also used to control microbial growth. These chemicals are used to destroy the structures of microorganisms structure, and they are known as chemical disinfectants or sterilants. Chemical disinfectants are often employed during decontamination process to remove pathogenic microorganisms from

the indoor space and create a clean environment (Rutala, 1997; Simmons, 1983; Spaulding, 1968).

One of the major nosocomial infections is *Clostridium difficile* with 20,193 cases reported in England between years 2009 and 2010 (HPA, 2010). Studies showed that improved room disinfection strategies are associated with reduced levels of *Clostridium difficile* infection (Boyce, 2007; Boyce *et al.*, 2008; Mayfield *et al.*, 2000; Wilcox *et al.*, 2003). Similar reductions in concentrations of active infectious microorganisms have been shown in other infectious sources when exposed to chemical disinfectants, such as methicilin-resistant *Staphylococcus aureus* (MRSA) (French *et al.*, 2004), multi-resistant gram-negative *bacilli* (Brun-Buisson *et al.*, 1989), and *Serratia marcescens* (Cullen *et al.*, 2005).

There are several common chemicals used for sterilization and disinfections, such as hydrogen peroxide, chlorine dioxide, peracetic acid and sodium hypochlorite (Simmons, 1983). The type of disinfectants used will depend upon the items or environment, due to corrosion effect that may be caused by disinfectants such as hydrogen peroxide (which corrodes copper, zinc and brass), chlorine dioxide (which corrodes aluminium, copper, brass, stainless steel and chrome) and peracetic acid (corrodes metal instruments) (Rutala and Weber, 1999b).

Gaseous or air decontaminations technologies are used for the treatment of airborne microorganisms. This is a process in which vapour or gas form of chemical disinfectants,

such as chlorine oxide and hydrogen peroxide, is generated to decontaminate the indoor air of specific areas. However, in order to improve the effectiveness of the decontamination process, manual clean up with detergent or disinfectant is always recommended for the surface of equipment or furniture in selected areas, especially when heavy contamination is projected (Pottage *et al.*, 2010). This is because medical and patient equipments have internal areas that can be contaminated and difficult to clean solely by vapor decontamination (Andersen, Rasch, andHochlin, 2006).

There are not many studies which are devoted on air decontamination using organic disinfectants. The available studies are focused on plant (Cornejo *et al.*, 1999), and biofiltration (Roy *et al.*, 2003). Tea tree oil exhibits antimicrobial effects toward some common microorganisms, namely, *Staphylococcus aureus*, *Staph. epidermidis* and *Propionibacterium acnes* (Raman *et al.*, 1995). Tea tree oil is non-corrosive, non-staining, economical and easy to use compared with chemical disinfectants (Olsen, 1997). In this dissertation, a study on an organic disinfectant (tea tree oil) is included in one section. This section involves an on-site study of vapour decontamination using tea tree oil towards bacteria, yeast and mould.

2. 9 Summary

A literature review is carried out on the indoor air quality of healthcare facilities. In this review, the importance of ventilation is identified and elaborated. Ventilation is one of the major factors to control indoor air contaminants, Sick Building Syndrome and occupant thermal comfort.

The indoor conditions in healthcare buildings are very different compared with other environments, such as an office space. These conditions affect the well-being of patients and the spread of infections. Engineering control employed in healthcare settings differs in terms of parameters and needs. In comparison with other temperate climates, there is a lack of IAQ studies in healthcare facilities, particularly in the tropics. This results from studies and guidelines of ventilation and IAQ published in countries of temperate climates.

Therefore, further investigation on the subject is needed to deepen the understanding of indoor air quality in healthcare facilities in tropical climates such as Malaysia.

In this dissertation, field studies are carried out to study the IAQ of Malaysian healthcare facilities. The studies are focused on a pharmaceutical laboratory building in Petaling Jaya, an unoccupied newly commissioned hospital in Kuching, and four hospitals that have long been in service around Selangor. The main aim of these studies is to determine the IAQ profiles for different healthcare buildings and conditions, i.e.

the IAQ of occupied and unoccupied hospitals. Vapour decontamination is tested to determine the antimicrobial properties of vapour form tea tree oil in indoor air control, especially for bioaerosol. More details regarding the research work will be explained in the following chapters.

Chapter 3. This chapter discusses the research methodologies used in Chapters Four through Seven.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 Overview

This chapter discusses the research methodologies used in the following chapters, namely, Chapters Four through Seven. The main study is divided into a few chapters based on their survey site and objectives. It shall be noted that the research methology may be slightly different based on the research objectives.

The study is conducted using the preliminary walkthrough procedure in the premises developed by Cheong and Chong (2001) for indoor air quality (IAQ) audit in air-conditioned premises, followed by physical measurements and subjective assessment.

The physical measurements include measurements of thermal comfort parameters such as air temperature (C°), relative humidity (RH%), air velocity (m/s), indoor contaminants which include formaldehyde (HCOH), carbon monoxide (CO), carbon dioxide (CO_2), total volatile organic compounds (TVOC), particulate matter (PM), and biological pollutants (bacteria, fungi and mould). For subjective assessment, questionnaires and interviews are conducted, which involve surveying the site staff to obtain a subjective feeling on the environment. The survey accounts for the effects of air quality on the health of the hospital staff. In addition to the IAQ audit, a simple simulation model is developed using FLOVENT software to predict the airflow distribution in one of the research areas, namely, pharmaceutical laboratory building.

3.1 Physical Measurements

The list of equipment used for physical measurements is shown in Appendix D.

3.1.1 Chemical Gaseous Contaminant Measurements

a) Kanomax IAQ Monitor Model 2111(CO and CO_2) (concentration in ppm)

Kanomax IAQ monitoring (model 2211) with ±3% accuracy for CO and CO_2 is used for chemical gaseous contaminant measurements. Firstly, the probe is connected into the probe terminal. The grip part of the probe is placed into the probe stand and the instrument is then powered on. Measurements are performed in "calculation mode". Following this, the sampling time, number of samples and data storage are set. Lastly, the measurement process is initiated and the results are recorded from the display when the measurement is stopped automatically. The steps are repeated for other locations.

b) ALNOR CompuFlow IAQ Meter CF930 (CO and CO_2) (concentration in ppm)

ALNOR CompuFlow IAQ meter (model CF930) is capable of measuring CO and CO_2 concentrations with an accuracy of ±3%. CO_2 is detected using dual-wavelength non-dispersive infrared, whereas CO is detected using an electro-chemical sensor. The instrument is first powered by pressing the ON/OFF key. The parameters are selected using the arrow key and TEST ID is recorded for the selected test zone in order to retrieve the data later using a computer. The display setup is capable of displaying three parameters with one primary and up to two secondary parameters selected at one time. Samplings is performed continuously with one TEST ID while the "ENTER" is pressed. Sampling is repeated at different locations by recording with different TEST ID.

c) Minirae 2000 Potable VOC (TVOC) (concentration in ppm)

Minirae 2000 Potable VOC Monitor (model PGM 7600) with ±10-20% reading accuracy is used to measure TVOC concentrations. The accuracy varies ±2 ppm or 10% for readings below 2000 ppm and ±20% for readings above 2000 ppm. Measurements are taken in "Survey Mode", which is initiated and ended manually. The equipment is first switched on. When the display exhibits 'Ready', measurements are initiated by pressing the [Y/+] button. The site ID is recorded for each measurement. The pump starts and the reading is displayed. Instantaneous readings of the gas concentration in ppm and the datalog information are saved automatically. The instrument is stopped after 10 minutes and the steps are repeated for other locations of measurement. The data are saved and retrieved afterward from the instrument via computer.

d) PPM Formaldemeter htV-m (HCOH) (concentration in ppm)

PPM Formaldemeter with 2% accuracy is used to measure HCOH concentrations. The instrument matches the NIOSH criterion for acceptability whereby all results should fall within the range of ±25%. It shall be highlighted that it is vital to read the operation manual thoroughly and learn from the instructor before operating the instruments. The devices are placed at different distances from the floor in order to ensure accuracy and integrity of measurements. The instrument is switched on and the readings are recorded from the display. Following this, the instrument is switched off and the steps are repeated for other locations in accordance to the identified points. The instrument needs to be calibrated at room temperature since HCOH evaporates at different rates at various temperatures.

3.1.2 Particulate Measurements

Particulate concentrations can be measured either from the amount of particles within a cubic meter of air or from the amount of total mass within a cubic meter of air.

a) TSI Aerotrak Handheld Airborne Particle Counter (concentration in particles per m^3)

The concentration of suspended particulates is measured using TSI Aerotrak Handheld Airborne Particle Counter. The instrument incorporate an isokinetic sampling probe containing laser diode as the light source. This device has a flow rate of 0.1 cfm (2.83 L/min) with ±5% accuracy. The counting efficiency is 50% for particle size of 0.3μm; 100% for particles more than 0.45μm. The device is set to record readings automatically and the data are retrieved using a computer in the laboratory. The number of air samples taken need to be set along with the names of sampling locations given by the user. The average values from the total air samples are used for result analysis.

b) TSI DuskTrak II Aerosol Monitor Model 8532 (dust in mg/m^3)

TSI DuskTrak II Aerosol Monitor (model 8532) is used to measure the level of dust in the air with an accuracy of ±0.1% of the measurement range or 0.001 mg/m^3, whichever is greater. This device capable of measuring particle sizes from approximately 0.1 to 10μm. The device can measure the mass of aerosol in the selected size, i.e. 10 μm by using different size-selective impactors. The device is run using the factory default setting of 3.0 L/min with ±5% flow accuracy. In this study, the device is used to measure the overall dust concentration in the air, in which the size-selective impactors are not used. Similar to the airborne particle counter, the number of air

samples taken need to be set with the location name given by the user.

3.1.3 Thermal Comfort Measurements

The thermal comfort parameters for indoor environment are measured using:

a) IAQ Monitor KANOMAX, Model 2211 (%RH and temperature)

The monitored parameters are relative humidity (RH) and air temperature (C°). IAQ Monitor (model 2111) is capable of measuring air temperature ranging from -20 to 60 ℃, with an accuracy of ±0.5 ℃. The instrument is able to measure the relative humidity of air within a range of 2-98%, with an accuracy of ±2% (2-80%RH) and ±3% (80-98%RH). The device is set to take readings and other parameters (CO and CO_2) automatically. The time and date shown inside the device need to be recorded so that the measured data can then be retrieved using a computer in the laboratory.

b) Alnor thermo-hygrometer TH720 (Air temperature and RH%)

Thermohygrometer (model TH720) can be used to measure air temperature and relative humidity. This instrument is capable of measuring air temperature within the range of 0-60 ℃, with accuracy of ±0.6 ℃ as well as air relative humidity within range of 5-95%, with an accuracy of ±3% RH. The instrument is switched on by pressing the ON/OFF key. The parameters are selected using the arrow key and the TEST ID is recorded for the selected test zone for data retrieval purposes using a computer. Sampling is performed continuously with one TEST ID until the “ENTER” button is pressed. Sampling is repeated for other sampling locations by recording with different

TEST ID. The data are downloaded into the computer using LogDat2 software.

c) Extech 407117 Mini Vane Thermo Anemometer (Air velocity and temperature)

Extech 407117 Heavy Duty Mini Vane CFM Thermo Anemometer is used to measure air velocity and temperature. Air velocity is measured using a low friction, ball-bearing vane, whereas temperature is measured using a precision thermistor. The air velocity can be measured from 0.80-12 m/s with an accuracy of ±2%, whereas the air temperature can be measured within a range from 0-80 ℃, with an accuracy of ±0.8 ℃. The equipment is first powered and the anemoneter records the velocity in m/s and temperature in ℃. This instrument does not auto log the data in memory, and therefore manual record is required in the form of a table. This device is then replaced by Alnor Thermal Anemometers (model AVM440-A) for more accurate device readings during the course of the research.

d) Alnor Thermal Anemometers AVM440-A (*Air velocity, temperature and RH%)*

Alnor thermal anemometer (model AVM440-A) is used to monitor air velocity, temperature and relative humidity. The anemometer is able to measure air velocity within the range of 0 to 30 m/s, with ±3% accuracy of measurement range or ±0.015 m/s, whichever is greater. The device is able to measure air temperature within the range of -18 to 93 ℃, with an accuracy of ±0.3 ℃ and can measure relative humidity of air within the range of 0 to 95% with an accuracy of ±3% RH. This device enables data logging. The display setup exhibits three parameters with test ID that needs to be recorded so that the data can be retrieved using computer at laboratory via LogDat2

software. Measurements at other selected sampling locations are repeated with different test ID.

3.1.4 Biological Contaminant Measurements

Biological sampling is carried out using a single stage SAS Super 100 air sampler. The medium used for the bacteria is Plate Count Agar (PCA), whereas the the medium used for yeast and mould is Sabouraud Dextrose Agar (SDA). The air sampler is able to draw air samples at a rate of 100 litre m^{-3} (with aspirate air accuracy of ±5%), and impact the PCA and SDA petri-dishes. Sampling is performed in a region of 75 - 120 cm above the floor (DOSH, 2005). The volume of air sampled varies according to the nature of air in the sampling area. The air volume taken for the operating theatre is 1000 litres, and the air volume is 500 litres for other non-critical areas. After sampling, the air samples are incubated at different conditions. The PCA petri-dishes are incubated at 37℃ for 48 hours, whereas the petri-dishes with SDA are incubated at 30℃ for 120 hours. The number of microorganisms in air samples are counted after incubation and the unit of measurement is in colony –forming units per cubic meter (CFU m^{-3}).

3.2 Subjective Measurements – Questionnaire Survey

The effects of air quality on the health of the staff are assessed subjectively. The assessment is conducted in the form of interviews and questionnaires. The questionnaire is divided into sections, namely activity level, clothing type, surrounding conditions and other aspects such as cleanliness and odour. Questionnaires are distributed to the staff concurrently with physical measurements. The questionnaire is shown in Appendix E.

3.3 CFD Analysis

FLOVENT is employed as the simulation programme. CFD simulations are used to examine the airflow distribution and effectiveness of the system by fulfilling the criterion of the room, such as reducing the risk of post-operative infections in operating rooms.

CFD analysis is used to analyze the air distribution for one of the selected drug chemical testing for Chromatography unit located within an air-conditioned pharmaceutical laboratory building (see Chapter 4). The design is believed to provide a clean workbench for drug testing. Information including the positions of furniture, instruments and air grilles are measured, and these data are converted into the simulation software.

The grid element chosen is a hexahedron mesh. Grid refinement is performed to improve accuracy in the computation and increase the mesh capability in reducing computational errors. This is achieved by using grid localization and depletion option deliberately to reduce and optimize the total grid cells of the model.

3.4 Research Description

3.4.1 IAQ Audit for an Air-conditioned Pharmaceutical Laboratory Building

This section discusses about the research carried out in a pharmaceutical laboratory building located in Petaling Jaya, Selangor. The IAQ conditions, thermal comfort level and air distribution inside the building are investigated. An IAQ audit is carried out to achieve these objectives, which include physical and objective measurements to identify the IAQ conditions of the building. Air distributions are simulated by FLOVENT software to study the functions of air distribution systems in a selected room inside the building.

A preliminary walkthrough is first carried out to identify suitable locations for the study. Discussions are held amongst the facility management team which is responsible for the operation and maintenance of air-conditioning and mechanical ventilation systems (ACMV) in the building. The background of the building, floor plan and distribution of the diffuser inlet and exhaust outlet are first identified.

Physical measurements are taken at 0.1, 0.6, 1.1 and 1.6m levels at each location, which represent the standing and seating occupant zone. The physical measurements taken in this study are CO, CO_2, HCOH, TVOC, particulate matter, temperature, relative humidity and air velocity. Subjective measurements are performed interviews and data collection from staff using questionnaires, as shown in Appendix E. One of the rooms for drug chemical testing is chosen for simulation analysis. For pre-simulation planning, all furniture and equipment inside the room as well as the occupancy of the laboratory

staff are studied and simplified according to the software's capabilities.

3.4.2 IAQ Assessment in a Newly Commissioned Healthcare Facility

An IAQ assessment is carried out at a newly commissioned healthcare facility in Kuching, Sarawak. The IAQ conditions and thermal comfort parameters for a newly commissioned healthcare facility in different areas are investigated. Recommendations and works are also carried on during this study to reduce the measured parameters to acceptable levels.

The IAQ assessment methodology is shown in Figure 5.2, which is carried out with similar preliminary walkthrough and discussions with the facility management team to acquire information for further analysis. Measurements for assessment are air temperature, air velocity, relative humidity, particulate matter, microbial contaminants (bacteria, fungus and mould) and chemical gaseous contaminants (CO, CO_2, HCOH and TVOC). Samples and measurements are taken at heights within the range of 75-120 cm above floor (DOSH, 2005).

For indoor air samples, at least one sample should be taken from each floor or from each area serviced by an AHU. The number of sampling points chosen for each zone is listed in Table 3.1. For outdoor air measurements, at least two samples should be taken at the entrance of the building or at the entrance of the fresh air intake (DOSH, 2005).

Table 3.1: Recommended numbers for sampling points (DOSH, 2005)

Area of building (m^2)	Minimum number of sampling points
3,000-4,999	8
5,000-9,999	12
10,000-14,999	15
15,000-19,999	18
20,000-29,000	21
30,000 or more	25

3.4.3 IAQ Study in Four Malaysian Hospitals

This section describes the study of indoor air condition such as thermal comfort and chemical gaseous contaminants in four selected hospitals. The hospitals chosen are categorized into two categories, namely, centralized ACMV and non-centralized ACMV. These selected hospitals are Hospital Selayang, Hospital Sungai Buloh, Hospital Banting and Hospital Kuala Kubu. The objective of this study is to investigate the IAQ profile and thermal comfort for different ACMV systems and buildings with different ages.

The IAQ audit methodology for four hospitals will explained further in Chapter 6. Preliminary walkthrough and discussions with the facility management team are performed to acquire information such as the background of buildings, floor plans and ACMV air distribution inside the buildings. Feedback from hospital occupants are collected from survey questionnaires, as shown in Appendix E, with the assistance of IAQ auditors.

The measurements taken for the IAQ audit are temperature, air velocity, relative

humidity and chemical gaseous contaminants (CO, CO_2, HCOH and TVOC). During the measurements, the sampling locations are observed for any apparent and potential pollutants sources, occupant activities within that area and locations for fresh air intake and exhaust outlet.

For thermal comfort study, the comfort temperature is calculated using the equation given by Nicol et al. (1994). A seven-scale thermal comfort sensation vote is used for the equation, whis is collected from the survey of hospital occupants. This is to identify the preferable temperature of hospital occupants, namely hospital, staff.

3.4.4 Tea Tree Oil Decontamination for Indoor Air Microbial Pollutants Control

Hot and humid climate in tropical countries favour the growth of indoor air microbial pollutants. This condition may be worsened when circulated air is used, as microbial contaminants may accumulate at the edges of wall sections, and distributed through centralized ACMV. Hence, the potential use of tea tree oil as an alternative disinfectant for decontaminating indoor air microbial pollutants is investigated. Tea tree oil is advantageous as the staff may handle the disinfectant easier and safer than other commonly used solvents, such as hydrogen peroxide.

Preliminary walkthrough and discussions with the facility management team are carried out at a selected healthcare facility in Kuching, Sarawak. The air samples are taken before and after vapour decontamination, along with other parameters such as air temperature, relative humidity and dust concentration for analysis. Samples and

measurements are taken at height within the range of 75-120 cm above the floor (DOSH, 2005). The air samples for microbial contaminant measurements have different amounts of air volume, based on location characteristics. 500 litres of air are sampled for non-critical areas, whereas 1000 litre of air are sampled for operating theatres and other critical areas.

Vapour decontamination is carried out using an electric fogging machine, which converts the liquid disinfectants (i.e. tea tree oil) into mist. The mist is used for decontaminating the indoor air via ventilation ducting from air handling unit (AHU) to the serving areas. AHU is left to run for 24 hours after decontamination before the second sampling is taken.

Chapter 4: The following chapter discusses on an IAQ audit for an air-conditioned pharmaceutical laboratory building. This building is special type of building, which is considered as a healthcare related facility. Currently, there are no studies in Malaysia which cover this type of building. The aim of the following chapter is to study the IAQ conditions, thermal comfort, and ventilation system within a pharmaceutical laboratory building in Malaysia.

CHAPTER 4

IAQ AUDIT FOR AN AIR-CONDITIONED PHARMACEUTICAL LABORATORY BUILDING

4.0 Abstract

This research is carried out in a pharmaceutical laboratory building located in Petaling Jaya, Selangor. The building was built in October 1978, in which the institution was established to implement quality control products. Beginning in 1985, this building is used to ensure the quality, efficacy and safety of pharmaceutical products. This is a four-storey building, in which the water tower is located at the top. The main areas of interest for this IAQ study are levels 2 and 4, which are the Chemistry unit and Chromatography unit, respectively. The Chemistry unit located at level 2 consists of 10 staff, with a male to female ratio of 1: 0.43, whereas the Chromatography unit wcomprises of 9 staff, having a male to female ratio of 1: 0.8. Detailed information is presented in Appendix C.

The results reveal that all gas contaminants are below the threshold limits recommended by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Dust particles do not fulfill the prescribedvalues given by Ministry of Health (Malaysia). Chromatography unit IAQ is generally better than the Chemistry unit. The average relative humidity of 60.5% slightly exceeds the ASHRAE threshold limit.

4.1 Overview

Pharmaceutical and research laboratory buildings are one of the crucial environments to be kept clean and comfortable at all times. The Indoor Environmental Quality (IEQ) in laboratory, which includes thermal and acoustical comfort, and Indoor Air Quality (IAQ), affects the working conditions, well-being, safety and health of the researchers. The IAQ methodology was developed since the last five years and underwent many refinements to establish comprehensive and accurate IAQ profiles for different buildings (Zuraimi and Tham, 2008).

Poor ventilation rates, air rate changes and airflow inside the laboratory will increase carbon dioxide (CO_2) levels inside the laboratories. Poor ventilation is related to asthma, mucosal irritation, dizziness, dry or irritated throat, irritated or itchy eyes, headaches, hoarseness or pain in throat, runny nose and dry, irritated stuffy nose. The air in the laboratories must be clean and can produce buffer room temperature at 24℃, with relative humidity (RH) maintained within the range of 30% - 60%. Furthermore, the air velocity must be kept within the range of 0.1 to 0.19 m/s. The low air velocity will certainly avoid draft and swirls that promote the recirculation of microbes and cause some diseases (Khodakarami and Knight, 2008).

Malaysia is a typical hot and humid country. Due to the differences in climates and practices for energy conservation, operations and maintenance of buildings, the HVAC&R design in buildings in the tropics may differ considerably from those reported in the open literature (Cheong & Chong, 2001). This fact presents an important

challenge because it is often difficult to determine what the 'normal' levels of pollutants in tropical buildings should be as the threshold for evaluation. Thus, direct measurements and subjective assessments for IAQ in tropical buildings are required. The air supplied to the laboratories within pharmaceutical building should be cleaner than the desired air quality outside the pharmacy in order to mitigate the generation of particulates inside the room. Unfortunately, studies on IAQ in pharmaceutical buildings are rare and hard to be found in open literatures. Therefore, the present research is conducted with a two-fold aims: the major aim is to examine the IAQ profile in a typical pharmaceutical building in Malaysia and the minor aim is to investigate the airborne profile in a typical room of the pharmaceutical building.

4.1.2 Theory Relevant to the Present Research

Nicol *et al.* (1994) used Equation (2.5) to estimate the comfort indoor temperature, T_c. The slope a^* is the slope or regression coeficient derived by Fanger (1970) in his climate chamber experiments, having a value of 0.33. By using the vote index number assigned to each thermal comfort level and the staff's vote result, the mean thermal sensation vote for both units, C_m (mean comfort vote) can be calculated using equation (2.4). The mean internal temperature, T_{gm}, calculated earlier is 21.45^{o}C for both laboratories.

$$\text{Mean Thermal Sensation}, C_m = \frac{\sum_{i=Cold}^{\text{Hot}} [\text{No. of Vote for sensation i} \times \text{sensation i index}]}{Total\ Vote} \quad \text{---- (2.4)}$$

$$Comfort\ temperature, T_C = T_{gm} + \frac{4 - C_m}{a*} \quad \text{----------(2.5)}$$

4.2 Research Methodology of IAQ Study

The study is conducted using the preliminary walk-through procedure in the premises followed by objective measurements and subjective assessment. The objective measurements include measurements of temperature, RH, air velocity, formaldehyde (HCOH), CO_2, total volatile organic compounds (TVOC) and particulate matter (PM). Questionnaires and interviews are conducted for subjective assessment. In addition to the IAQ audit, a simulation model is developed using FLOVENT software to predict the airflow pattern of the room in one of the survey areas.

4.3 Physical Measurements

4.3.1 Contaminants in the Building

The ANSI/ASHRAE Standard 62.1-2007 (ASHRAE, 2007a) recommends that healthy indoor air consists of CO_2 below 1000 ppm (DOSH, 2005) for 8 hours of continuous exposure. The average concentration of 830 ppm in the Chemistry unit (CU) and 479 ppm in Chromatography unit (KU) are well below both standards.

Figures 4.1 and 4.2 are the plan views of both laboratory units and the positions of diffusers and fume hoods. The number of occupants are similar for both laboratories, and thus occupancy is not the main reason for the high CO_2 level in the chemistry area. From Figures 4.1 and 4.2, it can be noticed that the amount of exhaust outlets for CU is less than KU. This may be one of the reasons for the high CO_2 level, which is attributed to the lack of sufficient air changes in the lab. Although the building interior underwent renovation in the past 32 years, the initial HVAC system does not match

with the current design. The exhaust air grilles are located mainly in the corridor, and the indoor air contaminant levels increase when the room is closed. It is clear that careful planning of renovation works is imperative. It shall be noted that this is a 100% fresh-air system. In addition, the fume hoods are installed with carbon filters to reduce chemical pollutants for air released without recirculation into the laboratory (Suppiah, 2010).

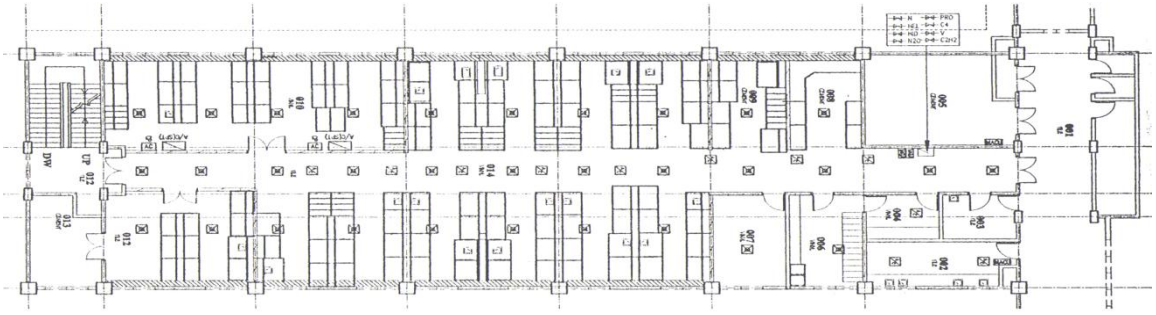


Figure 4.1: Floor Plan for Chromatography unit

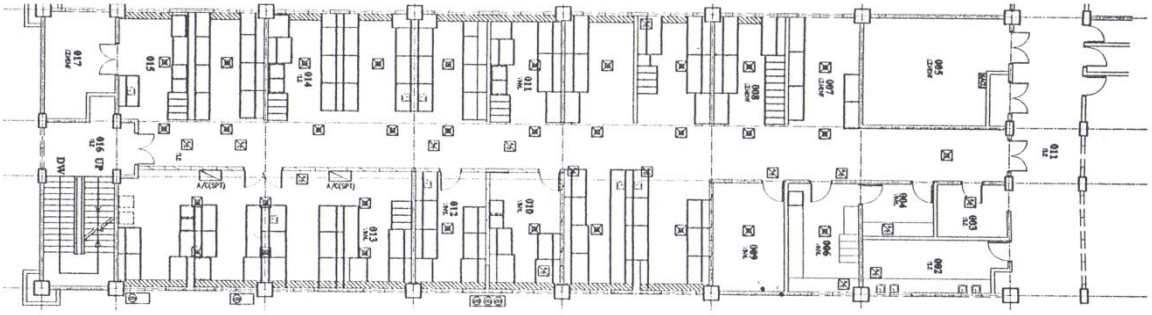


Figure 4.2: Floor Plan for Chemistry unit

The measurements reveal that CO varies from 1.4 to 1.6 ppm and 1.1 to 1.5 ppm in CU and KU, respectively. This result indicates that the CO level is well within the ASHRAE standard threshold of 9 ppm (ASHRAE, 2007a). It is observed that instruments are placed on the spot where measurements are taken, in which the instruments may be the source of CO. Ventilation can effectively decrease the risk of high formaldehyde concentrations (Nicholas and Guay, 2008). The HCOH

concentration varies from 0.023 - 0.047 ppm, which is below the limit of 0.1 ppm. The TVOC concentration is significantly low with an average value of 1.15 ppm for CU and 0.23 ppm for KU, in comparison to the TVOC limit of 3 ppm (ASHRAE, 2007a; DOSH, 2005). The gaseous contaminant level for CU is generally higher than KU. (See Appendix A)

Particles between 1-10 microns are classified as Respirable Suspended Particles. As the name implies, these particles are of a size that can be inhaled deep into the lungs. They are potentially hazardous, depending on the source of the particles (ASHRAE, 2009b). For example, tobacco smoke has a diameter ranging between 0.01 and 1 micron (ASHRAE, 2007a). ISO 14644-1(1999) cleanroom classification for laboratories area recommend at least ISO Class 8, which is the requirement set by Ministry of Health (MOH, 2007). Thus, laboratories are recommended to be maintained at ISO 8 (Low, 2010). The measurements on particulate matter and comparison with the ISO standard are sumarized in Table 4.1. (See Appendix A)

Table 4.1: Comparison on particles/ m^3 measured with ISO standard

	Maximum concentration limits (particles/m^3 of air)			
ISO 14644-1	0.3 µm	0.5 µm	1 µm	5 µm
Class 8	-	3.52 E+06	8.32E+05	2.93 E+04
Class 9	-	3.52 E+07	8.32E+06	2.93 E+05
	Particles per cubic meter (General Chemistry Unit)			
Minimum	7.86E+07	4.82E+06	8.10E+04	8.84E+03
Maximum	1.02E+08	7.2E+06	1.32E+05	1.49E+04
Average	9.19E+07	6.09E+06	1.03E+05	1.19E+04
	Particles per cubic meter (Chromatography Unit)			
Minimum	9.33E+07	6.06E+06	1.04E+05	1.28E+03
Maximum	1.04E+08	7.51E+06	1.38E+05	1.19E+04
Average	9.88E+07	6.89E+06	1.22E+05	5.21E+03

The results show that both laboratories are not within the acceptable range for class 8. External sources may contribute to the high particle level via inflitration through doors, windows and the HVAC system itself.

In order to identify the possible sources that contribute to the generation of particulate matter, a few samples are taken in a selected room within the Chromatography unit (Figure 4.3).

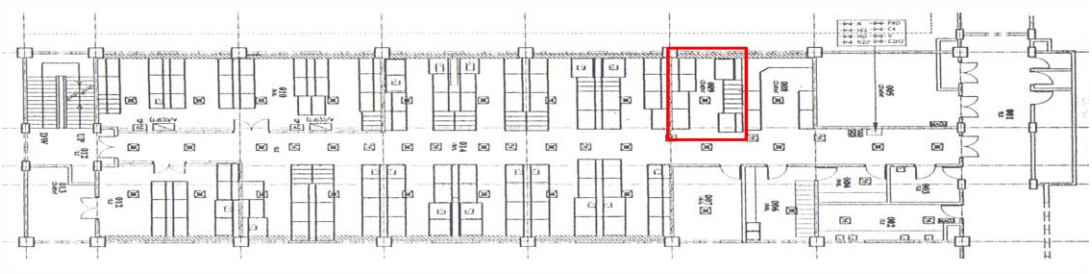


Figure 4.3: Selected room in chromatography unit

Measurements are taken at three points to identify the possible distribution of particulates from diffusers. The three points measured are at diffuser, 1m below diffuser and the centre of room, as shown in Figure 4.4.

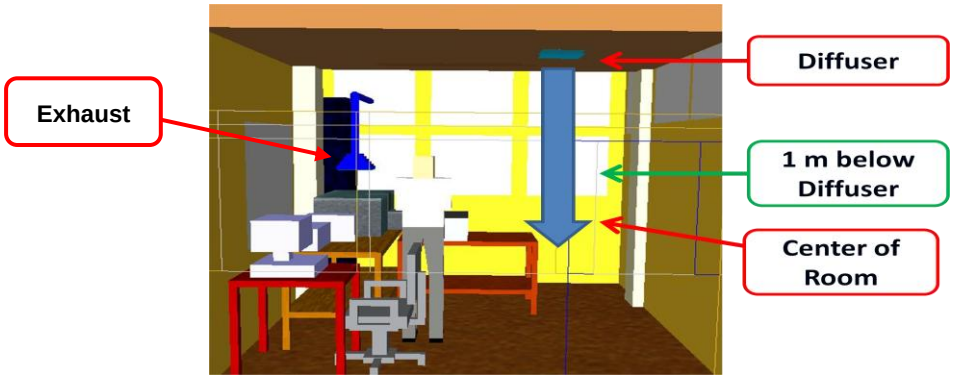


Figure 4.4: The measurements taken for different position in a selected room in chromatography unit

Table 4.2: Comparison on particles per cubic meter at different locations in a room

	Position	particles/m3 of air	
		0.5µm	5µm
1	1 m below diffuser	24527157	11479
2	Center of room	26940762	12396
3	Diffuser	43502960	16538

Table 4.2 shows the average values of particles from the room shown in Figure 4.4. From Table 4.2, it is found that higher particulate content is captured near the diffuser outlet compared to the centre of the room. This shows that the particulate matter is released from the diffuser rather than from the occupants. Therefore, the largest exterior source for the generation of particulate matter in the room is the outside makeup air entering the room. This implies that the fresh air penetrates the room, polluting the room instead of providing clean air.

4.3.2 Air Change Rate Evaluation

For laboratory buildings, the minimum clean space for pharmaceutical preparation areas should be class 8 (MOH, 2007). According to the ASHRAE Standard, the suggested air change rate follow ASHRAE for clean spaces is 12 – 18ACH (ISO class 9) and 25 – 35 ACH (ISO class 8) for 3 m height (ASHRAE, 2003a). Table 4.3 displays the room air velocities versus cleanliness class and correlation between room air velocity and ACH.

Table 4.3: Air changes per hour versus airflow velocities, room heights, and cleanliness class (ASHRAE, 2003b)

Class ISO 209	Average Room Velocity, m/s	Air Changes per Hour					
		2.5m ceiling	3m Ceiling	6m Ceiling	9m Ceiling	12m Ceiling	18m Ceiling
2	0.43 to 0.51	638 to 750	510 to 500	255 to 300	170 to 200	128 to 150	85 to 100
3 Class 1	0.36 to 0.43	525 to 838	420 to 510	210 to 244	140 to 170	105 to 128	70 to 85
4 Class 10	0.30 to 0.36	450 to 525	360 to 420	180 to 210	120 to 140	90 to 105	60 to 79
5 Class 100	0.23 to 0.28	338 to 413	270 to 330	135 to 165	90 to 110	68 to 83	45 to 55
6 Class 1000	0.13 to 0.18	166 to 263	150 to 210	75 to 105	50 to 70	28 to 53	25 to 35
7 Class 10,000	0.04 to 0.09	60 to 120	50 to 100	24 to 48	15 to 30	12 to 24	8 to 16
8 Class 100,000	0.02 to 0.04	30 to 45	25 to 35	12 to 16	8 to 12	8 to 9	4 to 6
9 Class 1,000,000	0.01 to 0.015	15 to 23	12 to 18	6 to 9	4 to 6	3 to 5	2 to 3

The total area served by AHU for both laboratory units estimated from the floor plan is almost similar. Each AHU serves about 1296 m^3 with a ceiling height of 3 m.

The supply air volume is given by:

$$Q = LxWxV \qquad \text{---------- (4.1)}$$

The air change rate is given as follows:

$$ACH = \frac{3600\ x\ Q}{LxWxH}$$

$$= \frac{3600\ x\ LWv}{LxWxH}$$

$$= \frac{3600\ x\ v}{H} \qquad \text{---------- (4.2)}$$

Equation (4.2) shows, under a certain velocity, the room ACH varies inversely with room height. Equation (4.3) is used to calculate the ACH supplies in two laboratories.

$$\text{Air change rate, } ACH = \frac{3600\,x\,Q}{Room\,Volume} \text{ ---------- (4.3)}$$

where Q = Supply air volume

and ACH = Air changes per hour

L = room length, m

W = room width, m

H = room height, m

v = room velocity, m/s

The supply air volume (Q_{CU}) is 3.82 m^3/s for the Chemistry unit. The air flow rate for The Chromatography unit (Q_{KU}) is found to be 4.03 m^3/s. From Equation (4.3), it is found that the air change rate for the Chemistry unit is 10.6 ACH, whereas the value is 11.2 ACH for Chromatography unit. Both units do not fulfill the minimum requirement for air change rate, whereby the Chromatography unit has a higher ACH values compared with the Chemistry unit. This may partially explains why the indoor contaminant level for Chemistry unit is higher than Chromatography unit, other than HVAC design.

4.3.3 Thermal Comfort Evaluation

The current study shows that the laboratory environment is not that humid. The average air RH is measured to be 60.5% and 63.1% for CU and KU, respectively, which exceed the maximum recommended level of 60% (ASHRAE, 2004). However, as reported by Zuraimi and Tham (2008), the outdoor air is usually hot (30^{o}C) and humid (90%) throughout the year. Therefore, the Singapore NEA standard (Bakhda, 2007) recommended 70% as the maximum allowable RH for indoor air. It is highlighted that

the Singapore standard is adopted in this study for the RH analysis. In the present research, the indoor air RH for both units is within the acceptable comfort level.

The average air velocity varies from 0 - 0.21 m/s and 0.03 - 0.21 m/s in CU and KU, respectively. The average velocity is obtained to be 0.11m/s for both units. The air velocity is below the ASHRAE (2004) and Singapore standard (Bakhda, 2007) of 0.25 ms^{-1}, and thus the staff would not feel any air draft at the centre of the room. The maximum velocity achieved is around 0.30 m/s, which is mainly due to the movement during measurements. The velocity is occasionally implied that the air is still air. Detailed data is shown in Appendix B.

4.4 Subjective Assessment Evaluation

The questionnaire survey is conducted to collect staff assessment regarding thermal comfort and other environmental factors. Questionnaire survey form is shown in Appendix E.

4.4.1 Comfort Temperature

The average temperature is only slightly below the recommended value (ASHRAE, 2004). Figures 4.5 and 4.6 show the staff activity level and thermal comfort level for the Chromatography unit, whereas Figures 4.7 and 4.8 exhibit the data for the Chemistry unit.

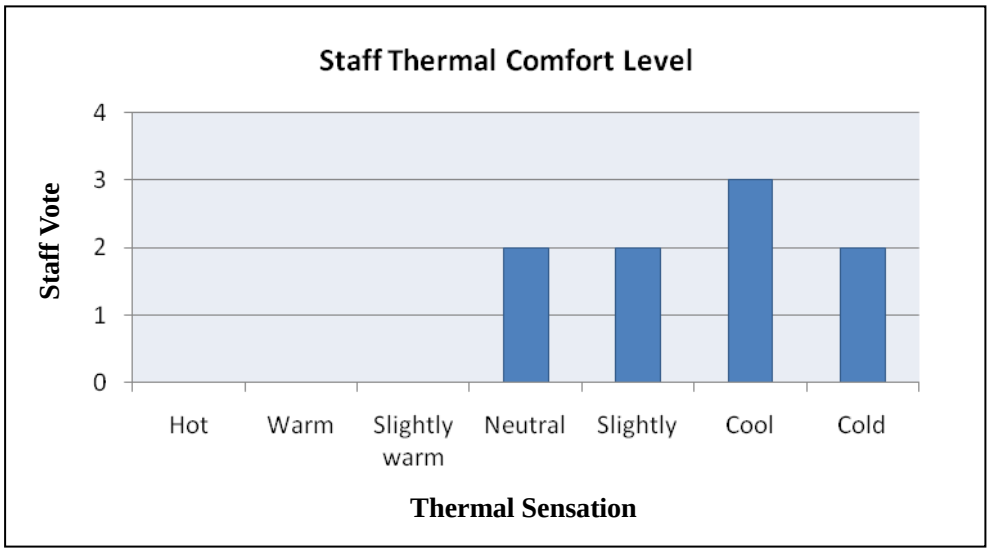


Figure 4.5: Survey chart for staff thermal comfort level in Chromatography Unit

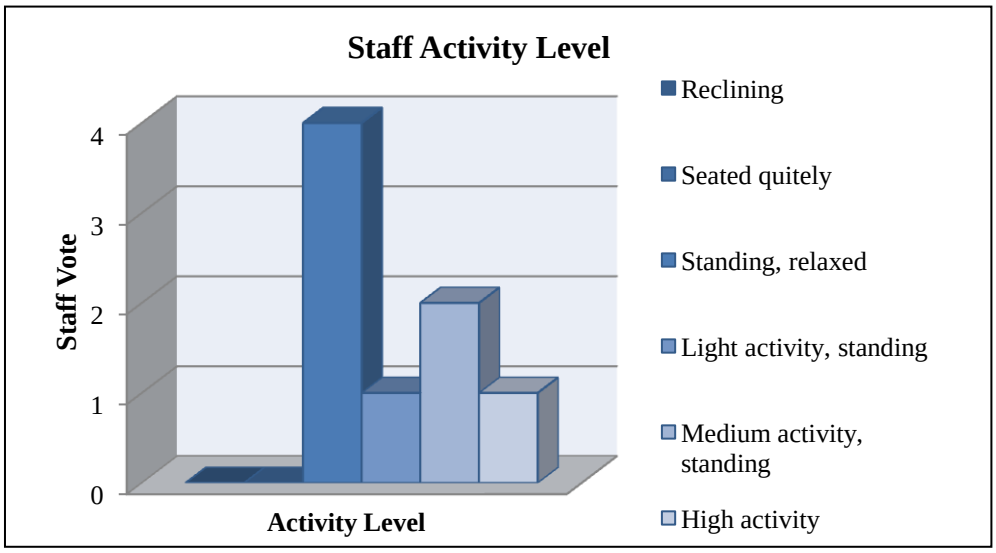


Figure 4.6: Survey chart for staff activity level in Chromatography Unit

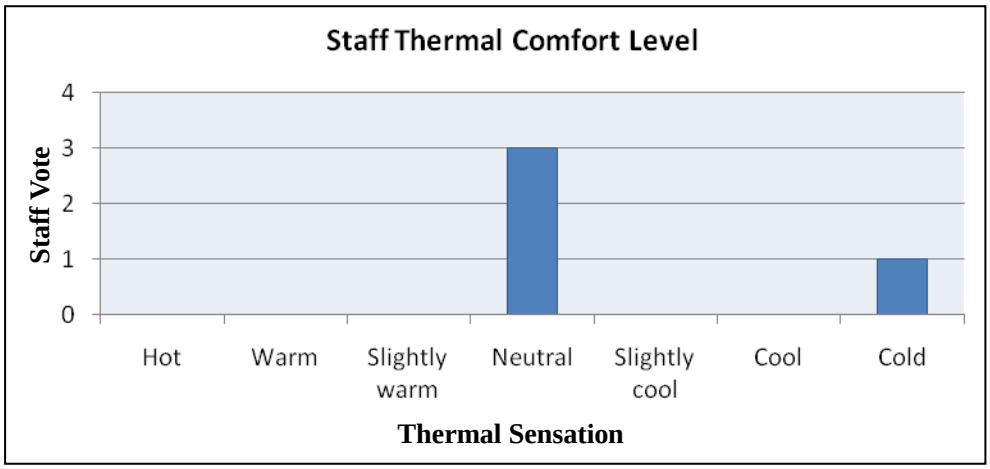


Figure 4.7: Survey chart for staff thermal comfort level in Chemistry Unit

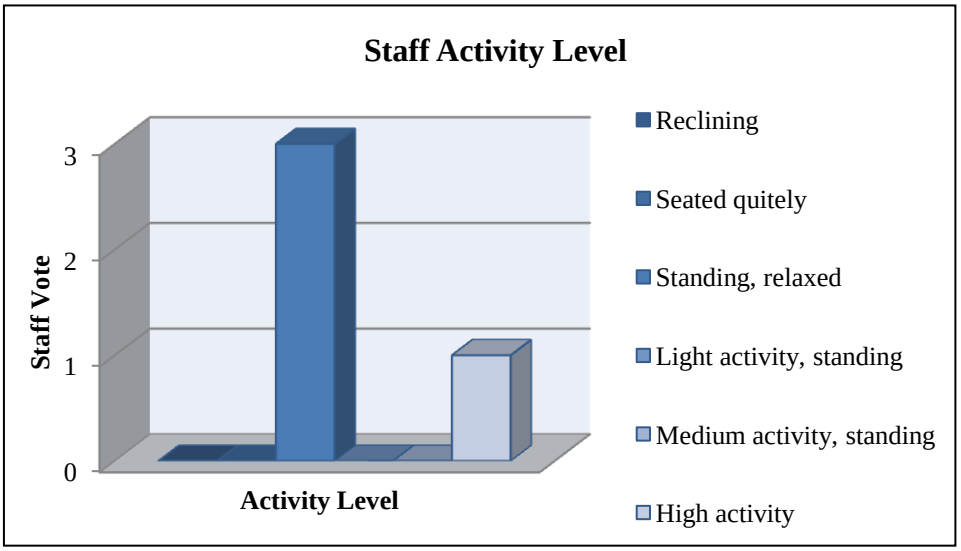


Figure 4.8: Survey chart for staff activity level in Chemistry Unit

From Figures 4.5 and 4.6, it is found that the thermal comfort for the Chromatography unit is biased toward the colder zone, although their activity levels are above average. The Chemistry unit, on the other hand, is satisfied with the current temperature setting, in which only one occupant feels cold. The mean thermal sensation vote is determined to be 2.44 and 3.25 for KU and CU respectively, using Equation (2.4). The recommended comfort temperature is calculated to be 26.13 ^{o}C and 23.69 ^{o}C for KU and CU respectively, using Equation (2.5).

From the current temperature of 22.4 ^{o}C (Chromatography unit) and 23 ^{o}C (Chemistry unit), the temperature is lower than the comfort temperature with difference of 3.7 ^{o}C and 0.69 ^{o}C lower for Chromatography unit and Chemistry unit respectively. The temperature should be set at about 24 ^{o}C for the overall room temperature.

For Chromatography unit,

$$\text{Mean Thermal Sensation}, C_m = \frac{\sum_{i=Cold}^{Hot}[\text{No. of Vote for sensation i} \times \text{sensation i index}]}{Total\ Vote}$$
$$= \frac{2*1+3*2+2*3+2*4+0*5+0*6+0*7}{0+0+0+2+2+3+2}$$
$$= 2.4444$$

$$\text{Comfort Temperature}, T_c = T_{gm} + (4 - C_{m)}) / a*$$
$$= 21.42 + (4 - 2.444) / 0.33$$
$$= 26.135^o C$$

For Chemistry unit,

$$\text{Mean Thermal Sensation}, C_m = \frac{\sum_{i=Cold}^{Hot}[\text{No. of Vote for sensation i} \times \text{sensation i index}]}{Total\ Vote}$$
$$= \frac{1*1+0*2+0*3+3*4+0*5+0*6+1*7}{1+0+0+3+0+0+0}$$
$$= 3.25$$

$$\text{Comfort Temperature}, T_c = T_{gm} + (4 - C_{m)}) / a*$$
$$= 21.42 + (4 - 3.25) / 0.33$$
$$= 23.69^o C$$

4.4.2 Air Velocity

In the current study, the air velocity is measured at many points in each room, which is normally occupied by staff. The air velocity in the chemistry unit varies from 0.00 to 0.21 m/s, whereas the value varies from 0.03 to 0.21m/s in the Chromatography unit. The average velocity is found to be 0.11 ms^{-1} for both units. The air velocity is below the maximum limit recommended by the ASHRAE (2004) and Singapore NEA (Bakhda, 2007) standards having a value of 0.25ms^{-1}. The maximum velocity measured can reach up to 0.30 m/s in a number of readings, which is attributed to human movement during measurements. In some occasions, the velocity is 0.00 m/s, which

indicate that the air is still and the staff may feel that the air is stuffy.

Draft is an undesired local cooling of the human body caused by air movement, as discribe in ASHRAE (2004). Draft can be annoying and the people sensing draft often demand higher air temperatures in the room or that the ventilation systems should be stopped. The conditioned air is supplied from the diffuser at a much higher velocity, and thus, the air velocity varies with the distance from the air diffuser. The average velocity and volumetric flow rate measured from the air diffuser outlet are obtained as 0.358 m/s (0.0896 m^3/s) for the Chemistry unit and 0.424 m/s (0.106 m^3/s) for Chromatography unit, respectively. The diffuser flow area is measured to be 0.25 m^2. Equation (4.4) is adopted from Faye (2005) to calculate the throw distance, whereby the maximum velocity in the jet has decreased to an the acceptable level of 0.25ms^{-1}. Assuming that the constant K is equal to 1 for the ceiling diffuser, the throw distance calculated is 0.8 m away from the diffuser. In other words, the staff that stays within 0.8 m distance from the diffuser will experience air draft because the velocity is higher than 0.25ms^{-1}. However, it is found that this parameter is acceptable for both units because the height is more than 2 m.

$$\text{Throw distance, } x = \frac{1.13KQ_o}{\bar{V}_x\sqrt{A_o}} \quad \text{---------- (4.4)}$$

$$= \frac{1.13\times1\times0.0896}{0.25\times\sqrt{0.25}}$$
$$= 0.81$$

4.4.3 Staff Symptoms (Air Quality Effects)

In the KU, 44.1% of the staff claim that they experienced dry skin symptoms, 44.1% experience dry or irritated throats and 34.1% vote for dry eyes. However, in the CU, 60% of the staff claim that they experience dry skin symptoms, 30% felt dry or irritated throats and dry eyes. These three symptoms are normally found in dry air environments. However, it is found from field measurement analysis, that the RH in the laboratory is higher than the recommended maximum value of 60% (ASHRAE, 2004). Howver, the value is within the comfortable zone (<70%) compared with the Singapore standard (ENV, 1996). Overall, the air humidity in the laboratory is biased towards the high limit.

This contradictory result was also highlighted by Cheong and Chong (2001). This is due to the fact that people in the tropics are accustomed to the high humidity levels outdoors (90%) and thus they have these dry symptoms although the RH is considered very high by the standard (ASHRAE, 2004). The symptoms faced by the occupants and percentages of the vote are shown in Figure 4.9 and 4.10 for the Chemistry unit and Chromatography unit, respectively.

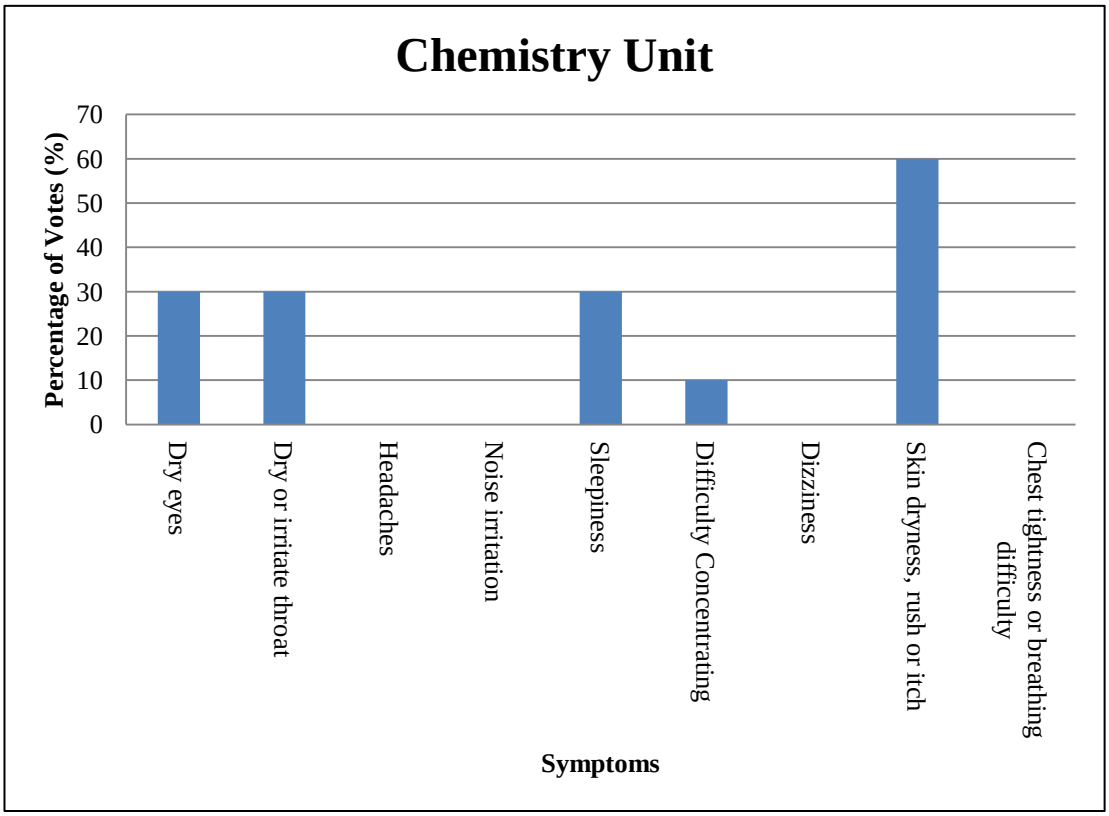


Figure 4.9: Survey chart for staff symptoms in Chemistry unit

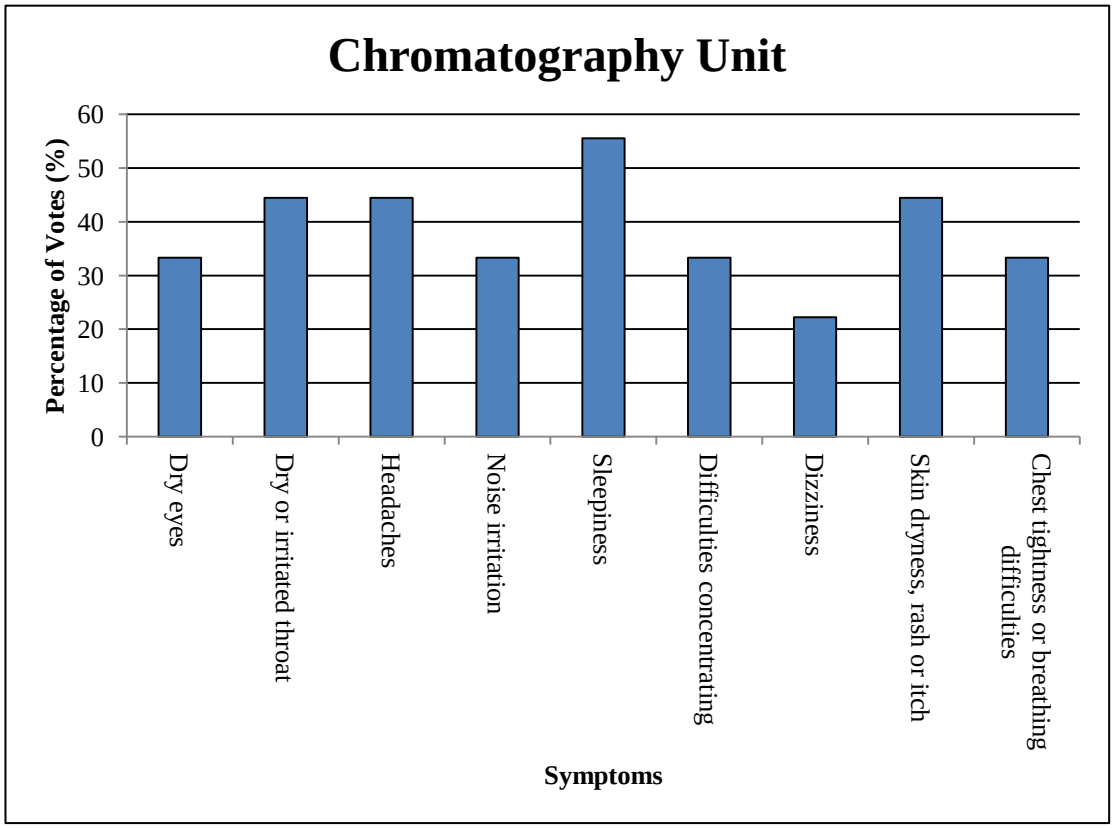


Figure 4.10: Survey chart for staff symptoms in Chromatography unit

4.4.4 Acoustic Level

There are 31% occupants from KU, who claim suffering from irritated noise. However, all occupants are satisfied with the sound level in CU. Figures 4.11 and 4.12 display the survey chart for acoustic level generated from two types of sources in the Chromatography unit and Chemistry unit, respectively. Generally, the noise generated is still within the acceptable range for both units, which is equal to vote 4 and below (Vote 4 is the average).

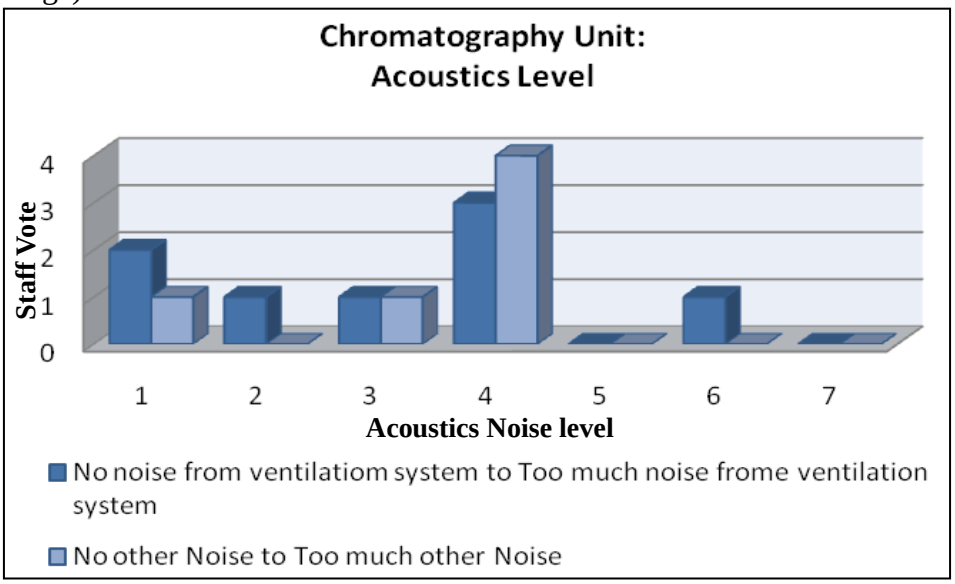


Figure 4.11: Survey chart for acoustic level in Chromatography unit

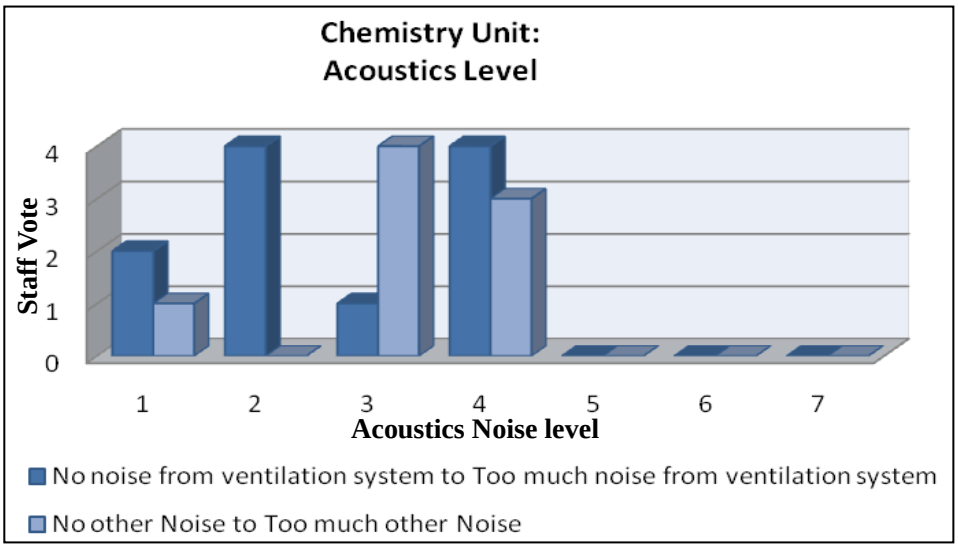


Figure 4.12: Survey chart for acoustic level in Chemistry unit

4.4.5 Air Movement

a) Chromatography Unit

The survey data for air movement and air quality in Chromatography unit are tabulated in Appendix C, Table C-5. The percentage bar chart for air movement is shown in Figure 4.13, and it can be seen that all staff experience a portion of air movement in the laboratory. In other words, they vote near the average value (3.5 at still to draughty scale). These results agree with the air velocity analysis output discussed earlier. Generally, 87.5% of the occupants are satisfied with the air movement inside the laboratory (with a scale of 3 to 5 for the votes).

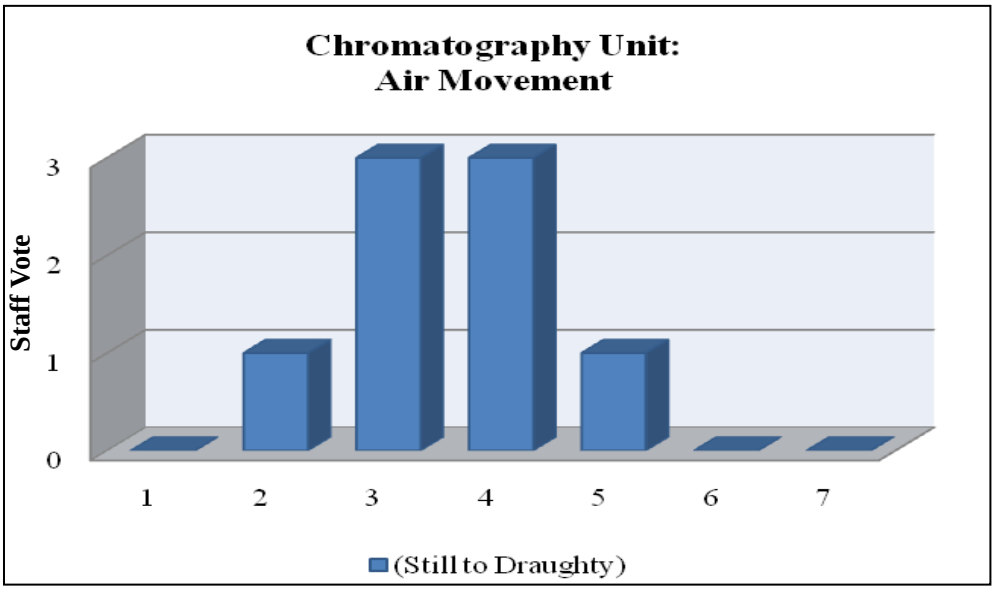


Figure 4.13: Survey chart for air movement in Chromatography unit

b) Chemistry Unit

The survey data for air movement and air quality in Chemistry unit are tabulated in Appendix C, Table C-6. The chart pattern (Figure 4.14) is almost similar to the Chromatography unit, with a 22% vote for still air, whereas other votes fall between the average. Generally, 77.8% of the occupants are satisfied with air movement inside the laboratory (with a scale of 3 to 5 for the votes), although the value is slightly lower than that for the Chromatography unit. In some occasions, air velocity of 0 m/s is measured, which means that the air is stuffy. This may be the reason why a number of occupants feel that the movement of air is still.

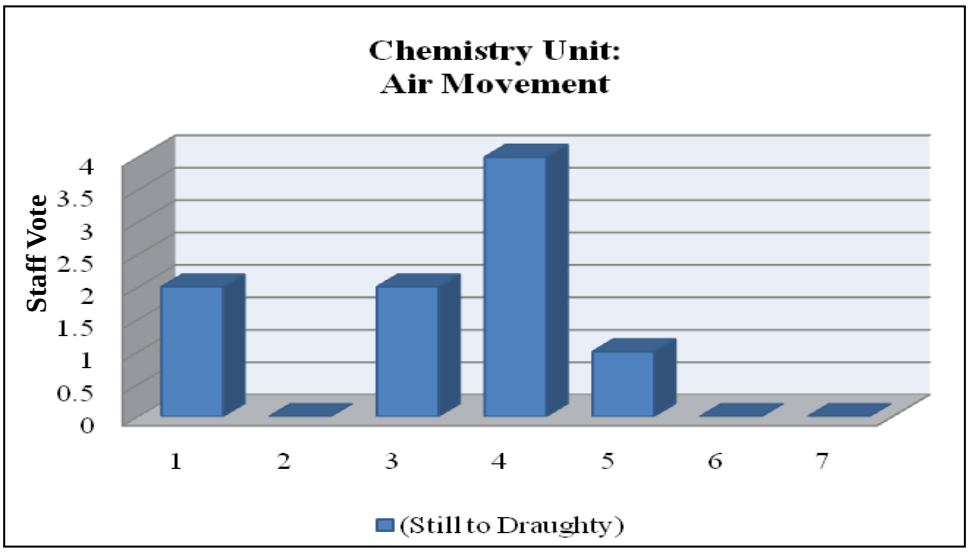


Figure 4.14: Survey chart for air movement in Chemistry unit

4.4.6 Air Quality

Overall, most of the staff are satisfied with the air quality in both laboratories. Figures 4.15 and 4.16 represent the survey chart for air quality in the Chromatography unit and Chemistry unit, respectively. It is shown that 85% of the occupants are satisfied with air quality in the Chromatography unit, whereas the number of occupants who are satisfied with the air quality for Chemistry unit is 85.7% (vote average and below).

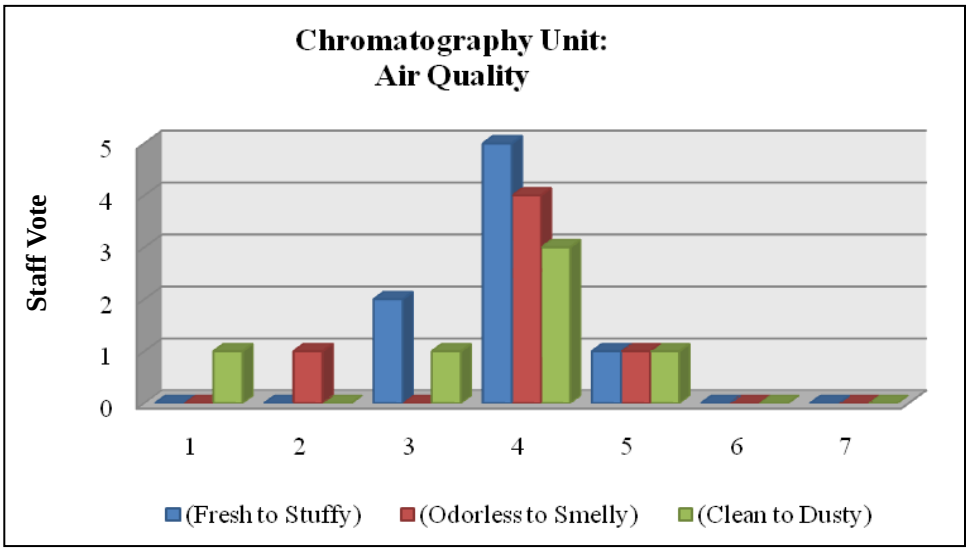


Figure 4.15: Survey chart for air quality in Chromatography unit

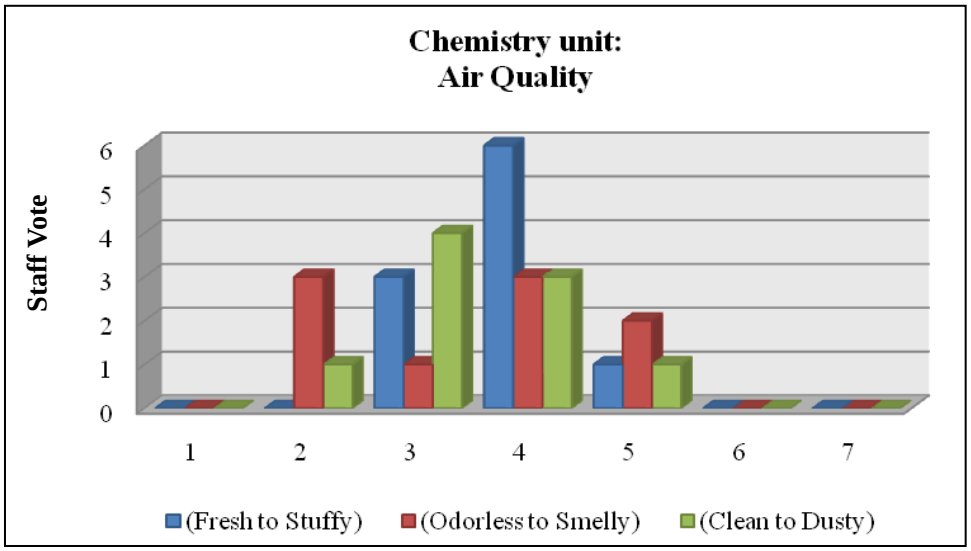


Figure 4.16: Survey chart for air quality in Chemistry unit

4.5 CFD Simulation

4.5.1 Simulation Model Description

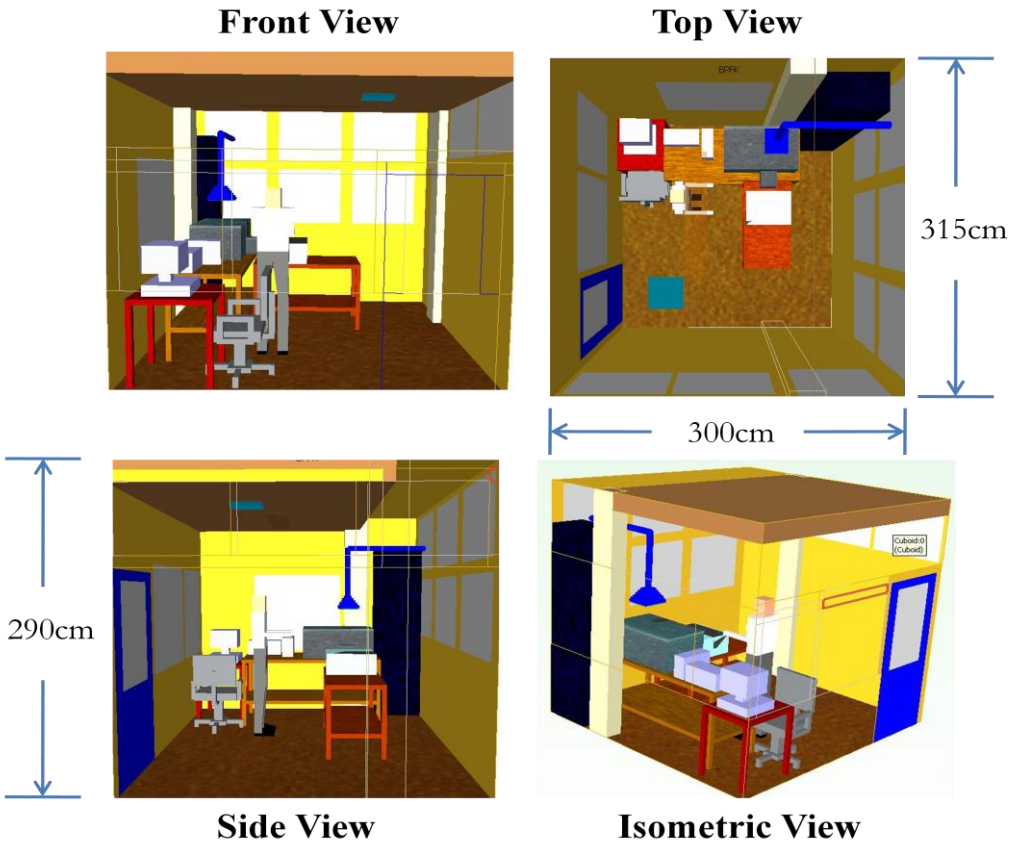


Figure 4.17: Simulation model from different views

In the present study, a 27.4m ^{3} (967.6 ft ^{3}) laboratory room with one occupant is simulated using CFD software, as shown in Figure 4.17. The ventilation air is supplied from a four-way-spread type ceiling supply diffuser (0.3m×0.3m) and returned from the return grille (0.15m×0.21m) located on top of the equipment. The air supplied from the diffuser is 1040 m ^{3}/h, the set point temperature is 24.0 ℃ and the RH is 72.1%. CO_2 is chosen as a tracer gas, in which the initial values at the diffuser outlet is 926ppm. The size of particulates is chosen to be 1 micron and the particulates are assumed to be released from the diffuser outlet with a concentration of 2 ppm.

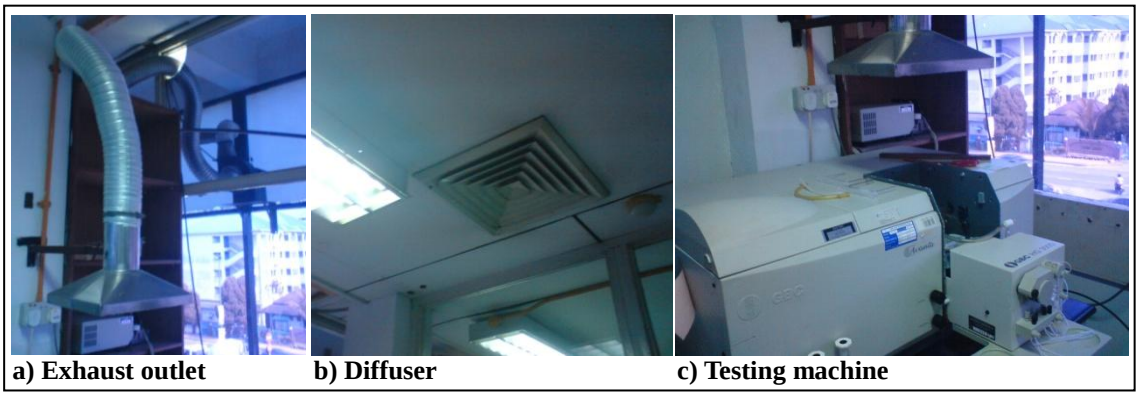


Figure 4.18: Exhaust outlet and diffuser inside the room

Figure 4.18 shows the exhaust outlet and diffuser inside the room. While Figure 4.19 and 4.20 shows the air distribution pattern inside the room. Figures 4.21 through 4.23 exhibit the velocity field， mass fraction field for CO_2 and particulate contaminants for heights of 0.6m, 1.1m and 1.7m, respectively.

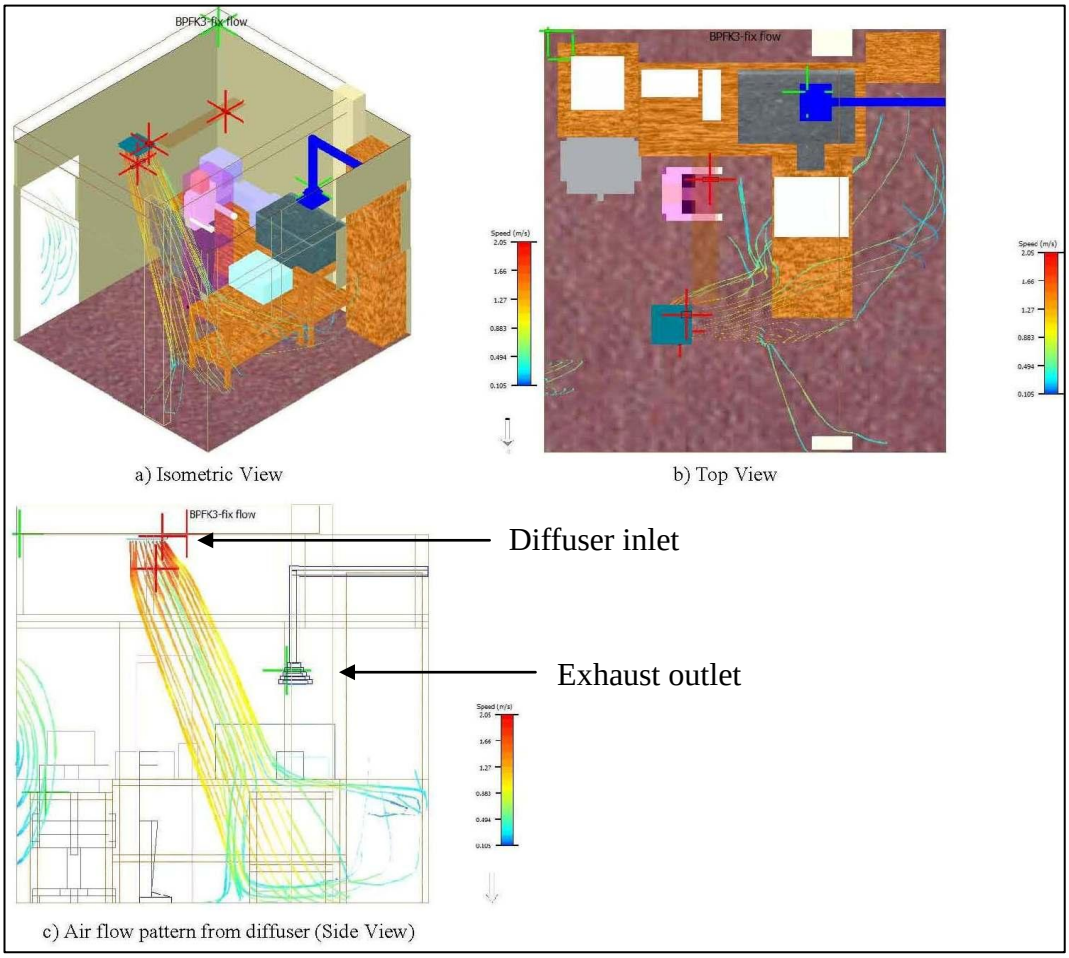


Figure 4.19: Air distribution pattern inside the room

Figure 4.20: Airflow pattern in the selected room in (a) Isometric View, (b) Top View, and (c) Side View

4.5.2 Air Distribution Profile

Figure 4.20 reveals that the airflow exiting the diffuser does not flow directly downward. Rather, the airflow is inclined at some degree towards the inner portion of the room. This phenomenon is caused by the indirect air pressure from the opening door. The air is directed towards the table surface, which forms a source of contaminants, including airbornes, due to the disruption of the testing product.

From Figure 4.21, it can be seen that the air velocity decreases from 1.42 m/s at 1.7 m to 1.15m/s at 0.6 m from the ground. The air velocity disperses when the high speed region of the velocity profile moves towards the inner portion of the room, which is mainly due to the diffuser design and pressure from the opening door.

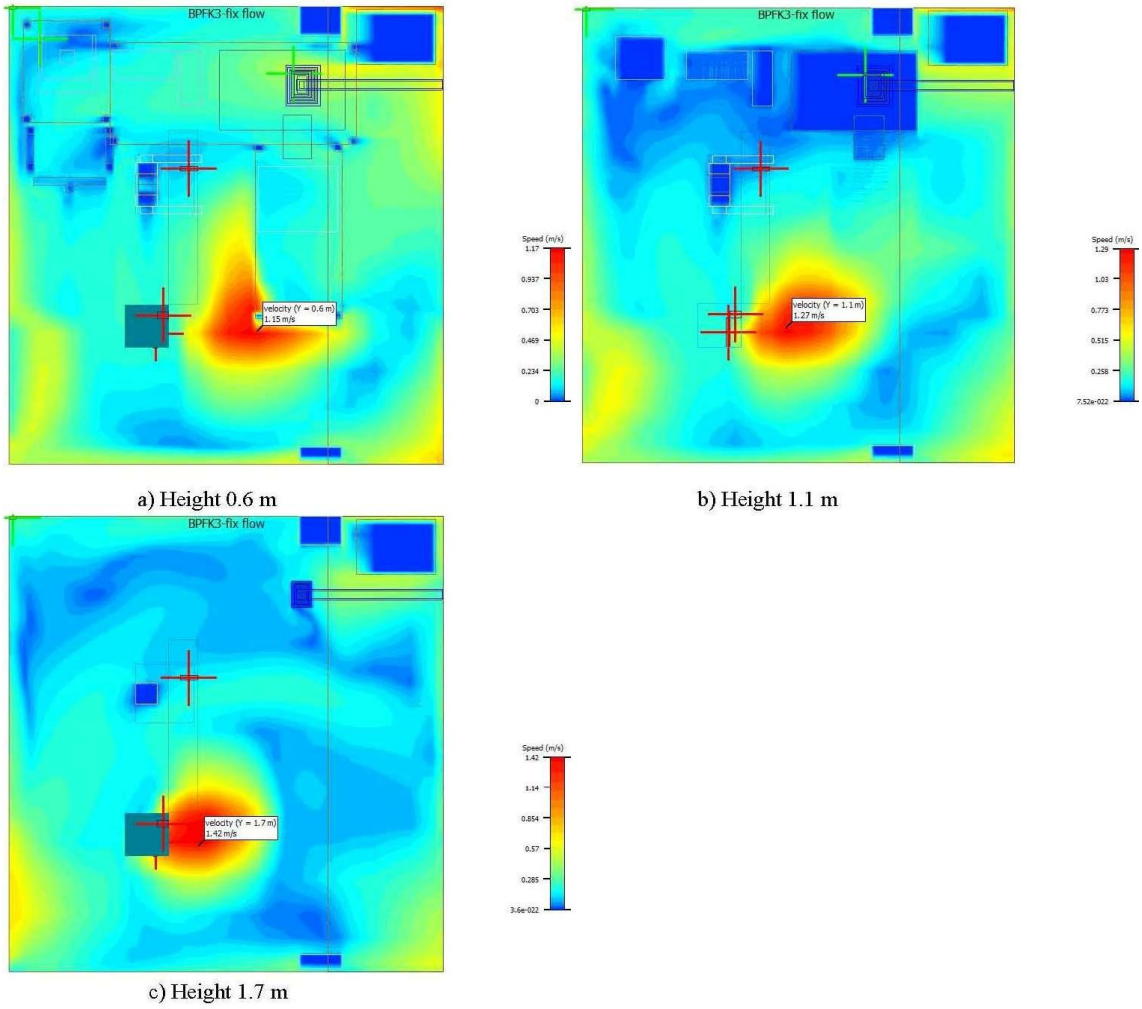
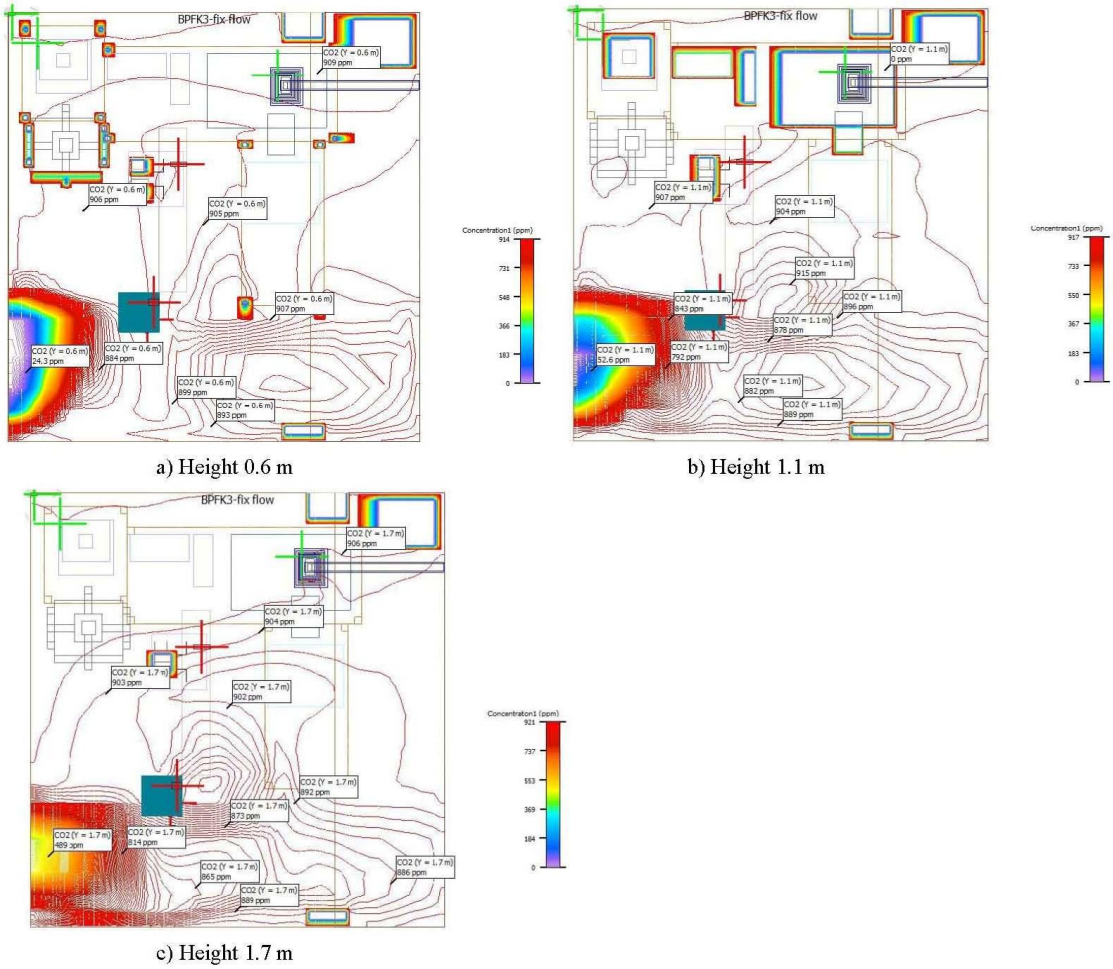


Figure 4.21: Velocity field in room at three heights (a) 0.6 m, (b) 1.1 m and (c) 1.7 m

4.5.3 Contaminant Mass Fraction Profile

Figures 4.22 through 4.25 represent the mass fraction field for CO_2, CO and particulate contaminants with a size of 1 and 5 micron. From the simulation results, it is observed that the concentration of the particulates or airbornes and tracer gas slightly increases towards the floor. Trapped air exists in the recirculation region at the corner, which may trigger the accumulation of contamination. Tables and equipment inside the laboratory act as barriers that enhance accumulation of contaminants before the contaminants are diluted through exhaust.



a) Height 0.6 m

b) Height 1.1 m

c) Height 1.7 m

Figure 4.22: Mass fraction profile of CO_2 at three heights (a) 0.6 m, (b) 1.1 m and (c) 1.7 m

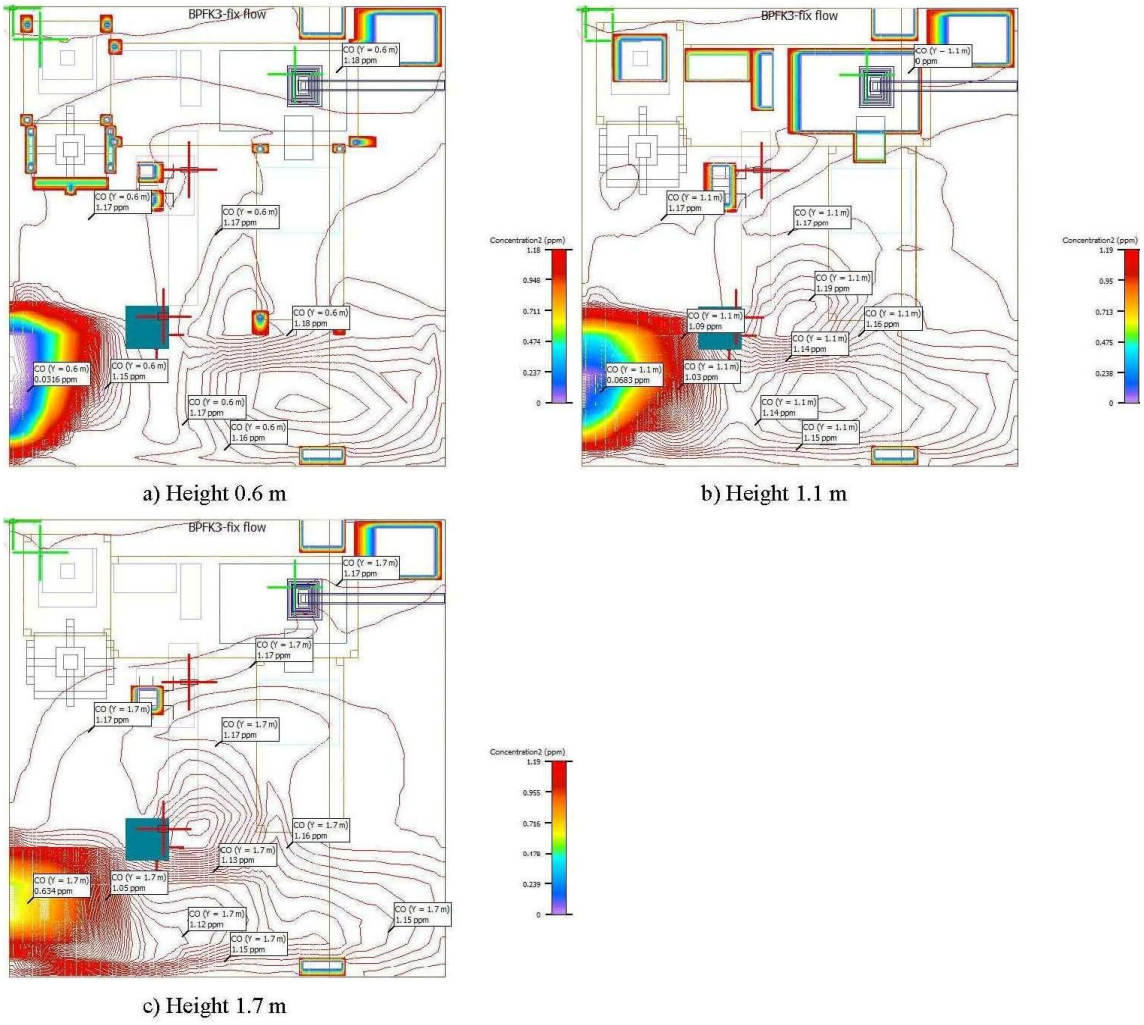
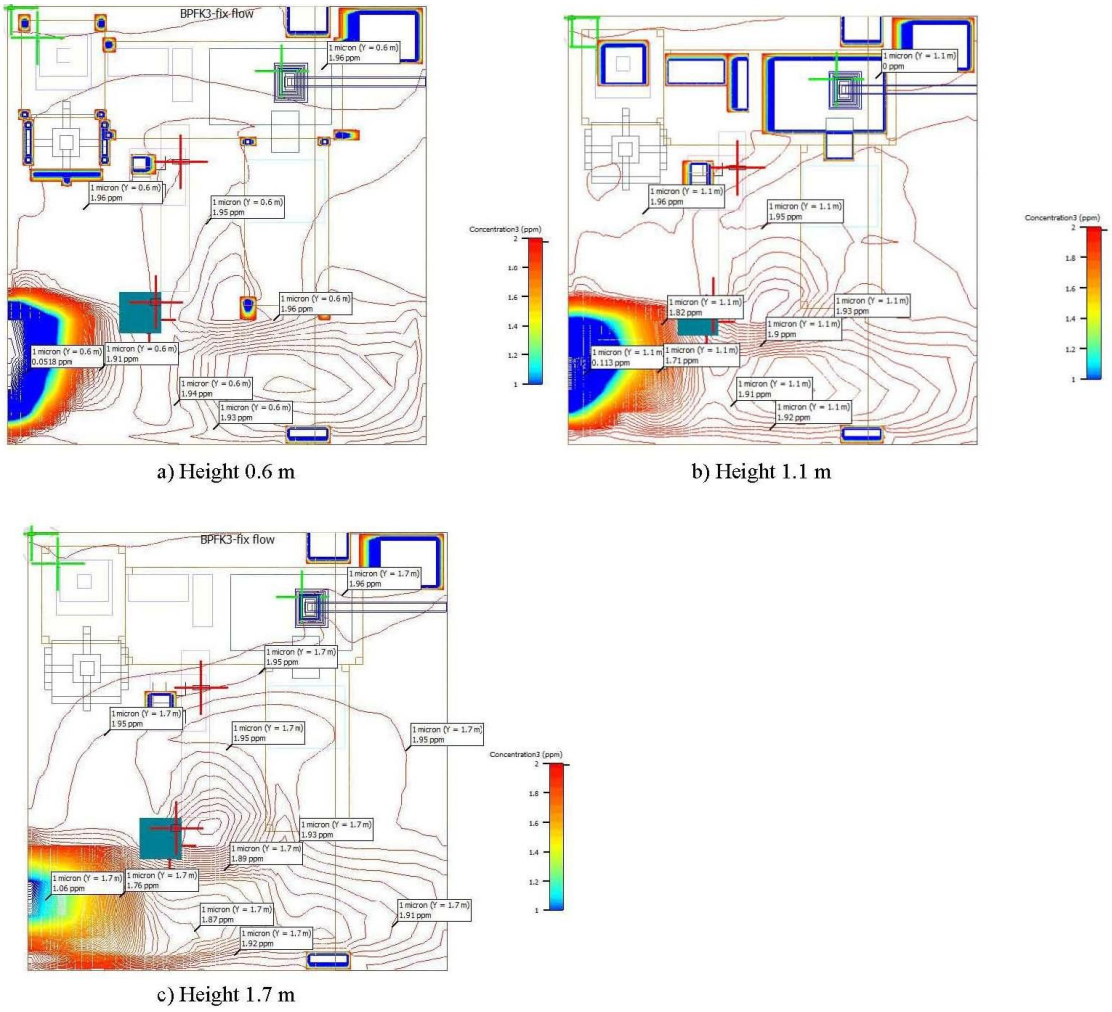


Figure 4.23: Mass fraction profile of CO at three heights (a) 0.6 m, (b) 1.1 m and (c) 1.7 m



a) Height 0.6 m

b) Height 1.1 m

c) Height 1.7 m

Figure 4.24: Mass fraction profile of 1 μm particulates at three heights (a) 0.6 m, (b) 1.1 m and (c) 1.7 m

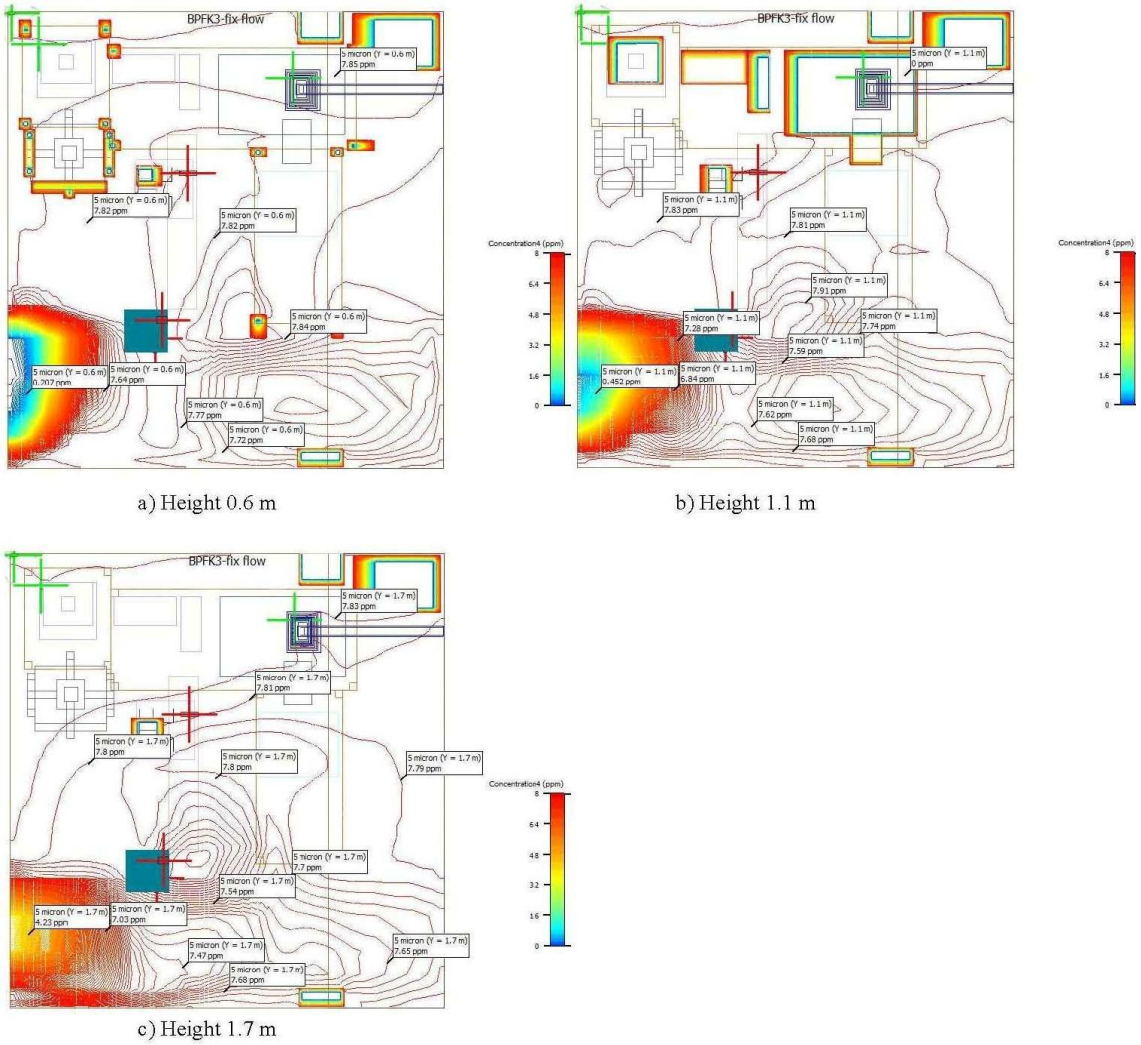


Figure 4.25: Mass fraction profile of 5 μm particulates at three heights (a) 0.6 m, (b) 1.1 m and (c) 1.7 m

4.6 Summary

The indoor environment needs to fulfill two basic requirements. The first requirement is the health risks and the second requirement is that, the indoor environment should be comfortable and pleasant. Another factor which needs to be fulfilled in laboratories is the environment required for the execution of tasks. There are several environmental factors governing the perception of comfort in space. A number of these factors are variations in temperature, relative humidity, air velocity in laboratories and indoor air pollutants. These pollutants include carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde (HCOH), total volatile organic compounds (TVOC), and particulate matter.

The results reveal that over 80% of the staff are satisfied with the air quality, lighting and noise level in the laboratory building. However, there are complaints regarding cold temperature, which is attributed to low activity or low clothing levels. People living in the tropics are generally adapted to high outdoor temperatures and high humidity levels. Hence, it is logical that they easily feel cold. Consequently, it is strongly recommended that the room temperature should be increased to 24 ^{o}C. This phenomenon also explains why more than half of the occupants still experience dry skin, dry throat and dry eye symptoms even though the humidity levels in the halls are high. The HVAC system in this building fails to provide sufficent ventilation to remove gaseous contaminants. It is impractical to reconstruct the whole HVAC system. However, external exhaust fumes can be added on the wall of each room to increase air circulation. The high particulate levels render this building unsuitable to function as a

pharmaceutical laboratory due to indequate of outdoor air provided for dilution and improper maintenance. Regular maintenance and careful examination need to be conducted with regards to filtering and clean air to ensure that air supplied into the room is cleaner to mitigate the generation of particulates.

Chapter 5. Chapter 5 extends the study of IAQ assessment in a newly commissioned healthcare facility in East Malaysia. Unlike Chapter 4 which focuses on a specific function building type (i.e. pharmaceutical), Chapter 5 assesses the IAQ profile in all clinical areas of a hospital. This study facilitates the understanding of the IAQ conditions before the hospital is occupied, as well as during the assessment.

CHAPTER 5

IAQ ASSESSMENT IN A NEWLY COMMISSIONED HEALTHCARE FACILITY IN EAST MALAYSIA

5.0 Abstract

A detailed investigation on the indoor air quality (IAQ) of a fully air-conditioned eight-storey healthcare building in East Malaysia is carried out. The assessment consists of examination of thermal comfort parameters (temperature and relative humidity), microbial pollutants, dust particles and the concentrations of carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde (HCOH) and total volatile organic compounds (TVOC).

5.1 Overview

Energy savings and maintaining a good indoor air quality (IAQ) are contradictious. The latter requires ample fresh air in order to dilute the air inside the building whilst former encourage minimizing the use of outdoor air whenever available. In the tropics, the moisture content in the air is relatively higher than other climates. For a normal day, the relative humidity can easily reach 50-70 % RH. The introduction of fresh air requires a huge demand of energy to dehumidify the moisture content before the air enters the occupancy zone. The concession in reducing the amount of outdoor air is that the outdoor can be mixed minimally with the return air as long as the outdoor air and return air proportion is enough to maintain the desirable IAQ. In healthcare buildings, there are areas which permit air mixing. However, air mixing is prohibited in critical areas such as

operating theatres and intensive care units.

Ventilation systems perform important tasks nowadays in removing pollutants from the air space in order to maintain good indoor air quality (IAQ). Dust serves as good growth and transport medium for microorganisms in an air-conditioned space (Korpi *et al.*, 1997). Laboratory tests revealed that small dust particles or virus-laden aerosols can remain suspended in the air long enough to be dispersed for long distances, making them a possible airborne carrier (Well, 1955). This statement is supported by the work of Riley *et al.* (1962), which performed animal tests in a tuberculosis ward, as well as theoretical analysis by Nardell *et al.* (1991), and population studies by Menzies *et al.* (2000). Thus, ventilation systems bring a significant influence for infection control in hospital ventilation.

There are studies which show that IAQ in buildings are greatly related to the Sick Building syndrome (Fisk *et al.*, 2009; Takeda *et al.*, 2009). More researchers are paying attention to this issue and numerous studies on indoor environment are carried out in tropical climates (Cheong and Chong, 2001; Cheong and Lau, 2003; Sekhar and Willem, 2004) and other regions (Dascalaki *et al.*, 2008; Hellgren et *al.*, 2011; Kwon, 2008; Tárnoki *et al.*, 2010) . However, there is not much research on IAQ assessment for healthcare buildings in Malaysia.

IAQ assessment in healthcare facility is applied based on the IAQ assessment methodology developed by Cheong and Chong (2001). IAQ assessment is carried out at

an eight-storey healthcare building in East Malaysia. The assessment is divided into two categories in order to determine the building indoor air quality for critical and non-critical areas.

5.2 Test Building

The healthcare building was launched for construction in 1998 and completed in three years. The building is a fully air-conditioned eight-storey building with roof level. The building can be categorized into critical and non-critical areas. The overall floor area of the healthcare facility is 41,450 m^2, with a non-critical area of about 35,741m^2.

The building comprises of a three-storey medical block, an eight-storey ward tower that accommodates 200 beds, three centres for cancer treatment, heart and kidney diseases, three specialist outpatient clinics, six operating theatres, and an imaging department.

The building does not contain a basement level. The first storey of the building consist of Information Technology (IT) Department, Medical Records Department, Cancer Centre, Pharmacy, Mortuary, laboratory, Materials Management and Waste Management, Laundry and Linen Service, Auditorium, and staff facilities. The second storey comprises of cafeteria, Physiotherapy Department, Wellness and Heart Centre, Kidney and Stone Centre, Imaging Department, Accident and Emergency Department, Special Outpatient Clinic (SOC) and general administration offices. The third storey includes Central Sterile Supply Department, Invasive Cardiac Laboratory, Cardiac

Catheterization Department and critical areas, namely operating theatre, Coronary Care Unit and Intensive Care Unit. The fourth throgh eighth storey consists of wards whereas the roof area on the tower serves for air-handling units and plant room.

In this building, chilled water for all AHUs is supplied through a centralized chilled water system. The chillers are situated outside the main building. Each department is served by at least one Air Handling Unit (AHU). The building has a total number of 72 AHUs, whereby 14 AHUs serve the critical areas (Table 5.2) located at level 3 of the eight-storey building. All AHUs in non-critical areas (Table 5.1) possess primary and secondary filters. The operating theatres contain high efficiency particulate air (HEPA) filters, before the air is supplied into the working space.

Table 5.1: List of non-critical areas

Level	Department	Working Area (m^2)	Level	Department	Working Area (m^2)
1	Pharmacy	622	2	Ward Entry & Public Amenities Lounge	3,343
	Materials Management & Waste Management	1,141		Nursing Admin Unit & PABX Unit	448
	Cancer Centre	2,229		Wellness Centre & Heart Centre	350
	Laboratory/Pathology Department	1,089		Accident & Emergency Ambulance Garage	933
	Medical Records Department	79		Cafeteria	840
	Administration	933		General Admin Station	467
	Catering Department	829		Kidney & Stone Centre	1,400
	Laundry/Linen Service	726		Medical Affairs Unit	207
	Mortuary	518		Doctor Offices	207
	Building Automation	512		Imaging Department	1,452
	Cleaning & Housekeeping	1,024		Physiotherapy	171
	Portering & Transporting Services	448		SOC 1, 2	1,037
	Staff Facilities	259		SOC 3	156
	Engineering Maintenance	363	4	Pediatric Ward	315
	IT Department	778		General Care & Day Surgery Ward	1,847
3	Executive Administration	518	5	General Care Ward	2,162
	Cardiac Catheterization	850	6	General Care Ward	2,162
	Central Sterile Supply Department	1,000	7	General Care Ward	2,162
			8	VIP Ward	2,162
Total Non-Critical Areas				35,741 m^2	

Table 5.2: List of critical areas

Level	Department	Code	Working Area (m^2)
3A	Coronary Care Unit & Intensive Care Unit	ICU/CCU	1,424
3B	Operating Theatres	OPT	2,279
Total Critical Areas			3,703

5.3 Indoor Air Quality (IAQ) Assessments

The IAQ assessment is performed using a systematic approach, as shown in Figure 5.1.

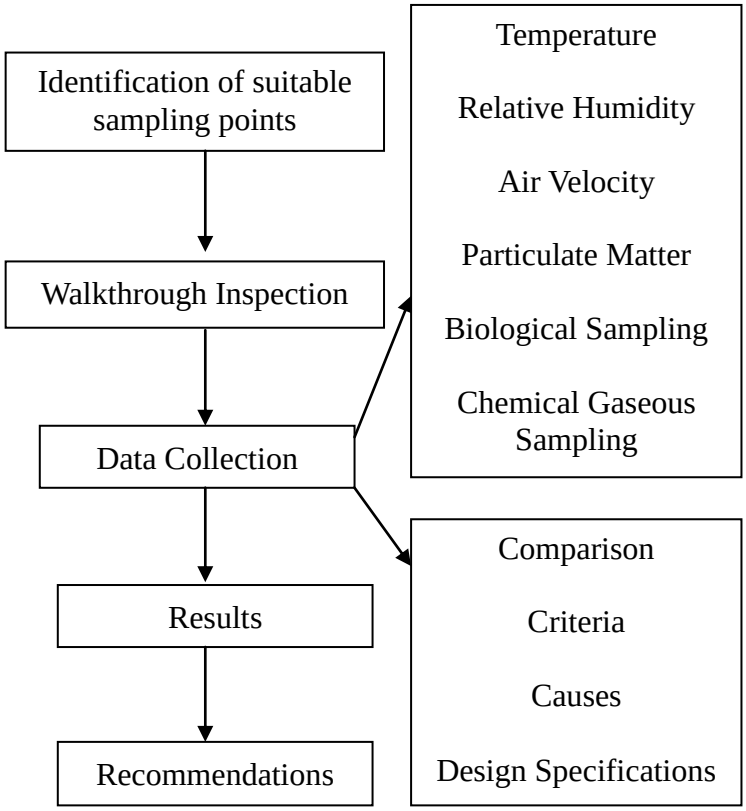


Figure 5.1: Methodology for IAQ assessment

The non-critical areas cover the entire building, excluding three departments, namely, Operating Theatres, Coronary Care Unit (CCU) and Intensive Care Unit (ICU). The non-critical areas are served by 58 dedicated AHUs. This is an empty environment without any staff occupying the building. However, the air-conditioning system is in operation. 65 IAQ sampling points are taken in non-critical areas for assessment.

The critical areas include three departments, namely, Operating Theatres, Coronary Care Unit (CCU) and Intensive Care Unit (ICU). Critical areas are served by 14 dedicated AHUs, with 22 IAQ sampling points are taken for assessment. Figures N-9 and N-10 (Appendix N) exhibit the sampling points locations for the third storey critical

areas.

The IAQ sampling positions and the number of sampling points are chosen based on the Code of Practice on Indoor Air Quality (DOSH, 2005). The sampling probe is located within a range of 75 to 120 cm from the floor at the centre of the occupied zone. For indoor air sampling points, at least one sample is selected from each floor or from an area serviced by separated AHU. For large floor space, the recommend minimum number of sampling points is 25 for an area of 30,000 m^2 area or more (building area: 39,444 m^2). For outdoor air samples, at least two samples are taken at the entrance of the building or at the entrance of fresh air intake.

5.3.1 Walkthrough inspection

An initial walkthrough is carried out prior to sampling. The intention of the walkthrough is to identify the potential sampling points according to AHUs serving area (DOSH, 2005) and location of the AHU. Upon identification of the sampling points, the available information and documentation such as floor plans and drawing of air-conditioning and mechanical ventilation (ACMV) systems are collected.

5.3.2 Chemical Measurements (CO, CO_2, HCOH and TVOC)

Chemical measurements of CO, CO_2, HCOH and TVOC concentrations are carried out at 65 indoor points. These points are measured by ALNOR Indoor Air Quality, (model CF930) for CO and CO_2, Portable VOC Monitor (model PGM-7600) for TVOC and Htv-M Formaldemeter for HCOH.

5.3.3 Thermal Comfort Measurements

The thermal comfort parameters of the indoor environment are measured using Alnor Thermo-Anemometer (model 440-A). This is a portable device used to measure the temperature, relative humidity and air velocity.

5.3.4 Particulate Contaminant Measurements

The concentration of the suspended particulates (total dust count) is measured using TSI DuskTrakII Aerosol Monitor (Model 8532).

5.3.5 Biological Samplings

Biological sampling is carried out using a single stage SAS Super 100 air sampler. The growth media used for incubation of bacteria and fungi are Plate Count Agar (PCA) and Sabouraud Dextrose Agar (SDA), respectively. The air sampler is capable of drawing air samples at a rate of 100 litre m^{-3} and impact the PCA and SDA petri-dish. Sampling is performed in a region of 75-120cm above the floor (DOSH, 2005). The volume of the sampled air is varied, depending on the nature of the air in the sampling area. The air volume taken for the operating theatre is 1000 litres whereby the volume is 500 litres for other critical areas. After collection, the air samples are incubated under different conditions. The PCA petri-dishes are incubated at 37 ℃ for 48 hours, where the SDA petri-dishes are incubated at 30 ℃ for 120 hours, before the colony forming units are counted. The air samples are counted after incubation and the unit of measurement is in colony-forming units per cubic meter (CFU m^{-3}).

5.4 Results and Discussion: Non-Critical Areas

Tables 5.3 through 5.5 present the indoor air quality assessment sampling locations based on AHUs. The sampling locations for assessment are shown in Appendix J.

Table 5.3: Measurements for non-critical areas: Level 1

Location Information				
LEVEL	DEPARTMENT	ROOM	AHU	Sampling Points
1	Material Management	Corridor	1-AHU-MMG	1-1
	Laundry	Flat Work	1-AHU-LDY	1-2
	Staff Facilities	Staff Change/Lockers	1-AHU-SFA	1-3
	Mortuary	Corridor in front of Muslim Body Storage	1-AHU-MOR	1-4
	Pharmacy	Ward Supply Dispensary Area	1-AHU-PHA	1-5
	Laboratory/ Pathology	Corridor Junction	1-AHU-LAB-1	1-6
		Main Biochemistry Lab	1-AHU-LAB-2	1-7
		Main Bacteriology Lab	1-AHU-LAB-2	1-8
	Administration	General Office (Finace)	1-AHU-AAA	1-9
		General Office (Admin & Operation)	1-AHU-AAA	1-10
	Medical Records	Medical Records	1-AHU-MDR	1-11
	I.T	Staff Rest Room	1-AHU-ITD-1	1-12
		CPU Server Room	1-AHU-ITD-1	1-13
	Cancer Centre	Nurse Base	1-AHU-CAC-1	1-14
		Corridor in front of Doctor Office 2	1-AHU-CAC-2	1-15
		Linear Accell. Room 1	1-AHU-CAC-3	1-16
		Linear Accell. Room 2	1-AHU-CAC-4	1-17
		Treatment Room	1-AHU-CAC-5	1-18
		Cyto Lab	1-AHU-CAC-6	1-19
		Isolation Room	1-AHU-CAC-ISOL	1-20

Table 5.4: Measurements for non-critical areas: Level 2

Location Information				
LEVEL	DEPARTMENT	ROOM	AHU	Sampling Points
2	Nursing Admin	General Office	2-AHU-TOW-1	2-1
		Main Waiting	2-AHU-TOW-2	2-2
	Wellness & Heart Centre	Treatment Room	2-AHU-WCC-1	2-3
		Between two Pat. Prep/Recovery	2-AHU-WCC-1	2-4
		Reception (Wellness)	2-AHU-WCC-2	2-5
	Kidney & Stone Centre	Nurse Base	2-AHU-KSC-1	2-6
		Treatment Room	2-AHU-KSC-2	2-7
	Physiotherapy	Between Gymnasium & Corridor	2-AHU-PHY	2-8
		Public Amenities (MPA)	2-AHU-PHY-CORR-1	2-9
		Public Amenities (MPA)	2-AHU-PHY-CORR-2	2-10
	SOC 1, 2 & 3	Treatment Room	2-AHU-OPD-1	2-11
		Treatment Room	2-AHU-OPD-2-1	2-12
	Accident & Emergency	Treatment Cubicles 2	2-AHU-ACE	2-13
	Doctor’s office	Corridor in front of Doctor's Office 3	2-AHU-SFA	2-14
		Corridor	2-AHU-SFA-CORR	2-15
	Imaging	Sub Wait Group 1	2-AHU-IMG-1	2-16
		General Radiography	2-AHU-IMG-1	2-17
		Equipt. Store	2-AHU-IMG-1	2-18
		Work Area Group	2-AHU-IMG-2	2-19
	General Admin	Admission Counter	2-AHU-AAA	2-20

Table 5.5: Measurements for non-critical areas: Levels 3 through 8

Location Information				
Level	DEPARTMENT	ROOM	AHU	Sampling Locations
3	Invasive Cardiac Laboratory	Invasive Cardiac Laboratory Room	3AHU-INV	3-1
	Cardiac Catheterization	Corridor	3AHU-CCL	3-2
	Central Sterile Supply	Ster Items Issue	3AHU-CSD-STERILE	3-3
		Main Packing Area	3AHU-CSD-L	3-4
	Executive Administration	Board Room	3AHU-AAA	3-5
4	General Care & Day Surgery Unit	Treatment Room	4-AHU-TOW-1	4-1
		Day Lounge	4-AHU-TOW-1	4-2
	Pediatric Ward	Corridor	4-AHU-TOW-2	4-3
		Corridor	4-AHU-TOW-2	4-4
5	General Care Ward	Treatment Room	5-AHU-TOW-1	5-1
		Day Lounge	5-AHU-TOW-1	5-2
		Corridor	5-AHU-TOW-2	5-3
		Corridor	5-AHU-TOW-2	5-4
6	General Care Ward	Treatment Room	6-AHU-TOW-1	6-1
		Day Lounge	6-AHU-TOW-1	6-2
		Corridor	6-AHU-TOW-2	6-3
		Corridor	6-AHU-TOW-2	6-4
7	General Care Ward	Treatment Room	7-AHU-TOW-1	7-1
		Day Lounge	7-AHU-TOW-1	7-2
		Corridor	7-AHU-TOW-2	7-3
		Corridor	7-AHU-TOW-2	7-4
8	VIP Ward	Treatment Room	8-AHU-TOW-1	8-1
		Day Lounge	8-AHU-TOW-1	8-2
		Corridor	8-AHU-TOW-2	8-3
		Corridor	8-AHU-TOW-2	8-4

5.4.1 Evaluation of Concentration of Indoor Air Pollutants

The chemical gaseous parameters for non-critical areas are presented in Figure 5.2. Details data are shown in Appendix H.

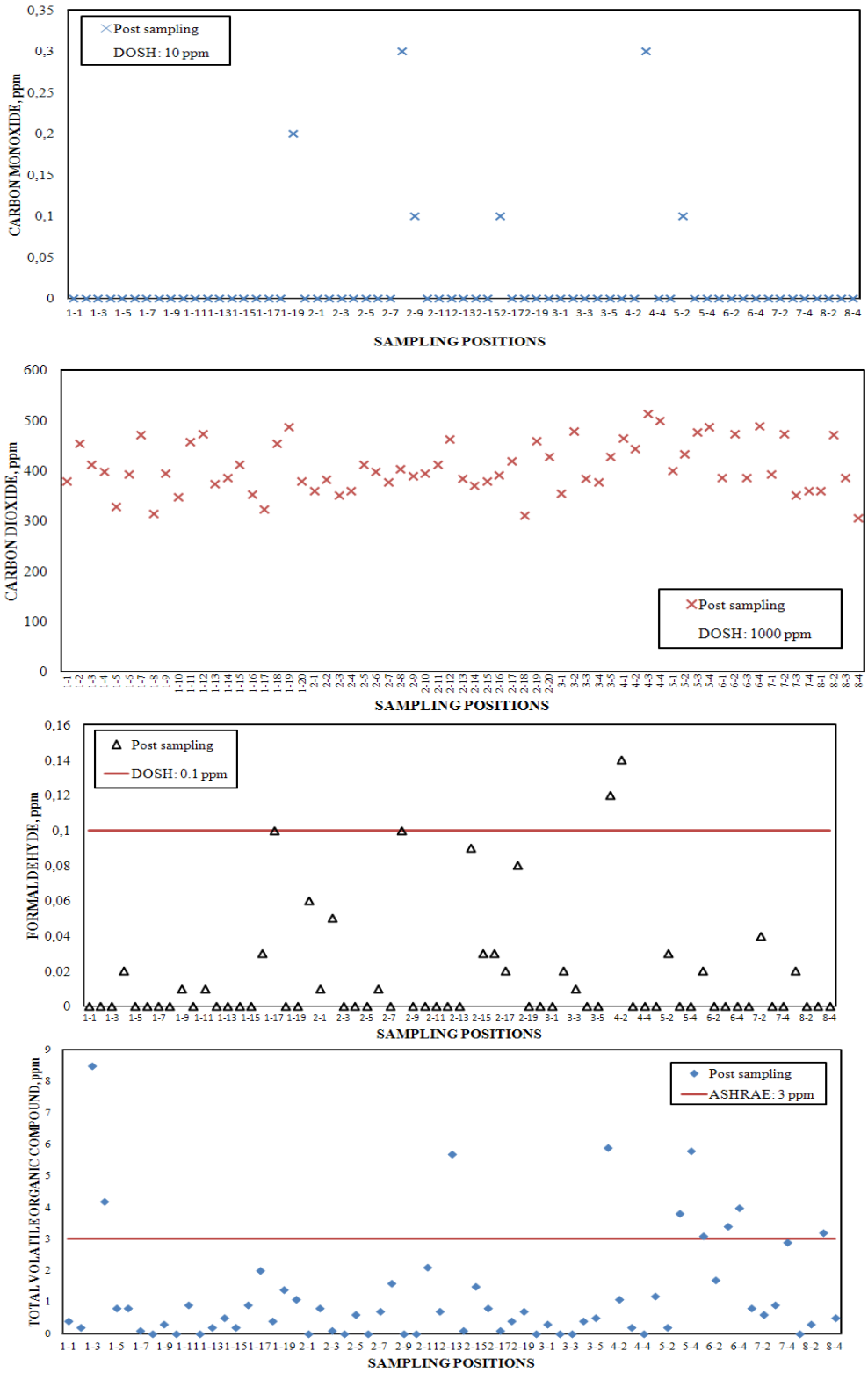


Figure 5.2: CO, CO_2, TVOCs and HCOH measurements

5.4.1.1 Carbon Dioxide

High carbon dioxide levels in indoor air may cause occupants to experience drowsiness, headaches, and feel sleepy. Human's respiration is the major indoor source of carbon dioxide. Indoor carbon dioxide level indicates the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity (ASHRAE, 2009). The concentration of carbon dioxide ranges between 305 and 513 ppm for the whole building. These values are well below the threshold limit suggested by the ASHRAE standards (ASHRAE, 2007), Malaysian Code of Practice on Indoor Air Quality (DOSH, 2005) and Singapore guidelines (ENV, 1996) having a recommended value of 1000 ppm.

5.4.1.2 Carbon Monoxide

Exposure to high levels of carbon monoxide can cause nausea and unconsciousness, and even death (ASHRAE, 2009). For safety purposes, the carbon monoxide levels should not exceed the limit of 10 ppm (DOSH, 2005) or 9 ppm (ASHRAE, 2007; ENV, 1996). Measurements of carbon monoxide concentrations range between 0 to 0.3 ppm for the whole building, and these value are fairly below recommended threshold.

5.4.1.3 Total Volatile Organic Compounds

Volatile organic compounds are gases emitted by a variety of chemical substances, some of which posses both short and long-term adverse health effects (ASHRAE, 2009). Concentrations of VOCs are consistently higher indoors (up to ten times higher) than outdoors. Examples of VOC emitting products include paint, building materials and furniture, office equipment such as photocopiers and printers, correction fluids, etc. The TVOC level should be limited below 3ppm (DOSH, 2005; ENV, 1996).

Most measurements in the building are within the threshold limit, except for 10 locations. These locations are 1-3, 1-4, 2-13, 4-1, 5-3, 5-4, 6-1, 6-3, 6-4 and 8-3. The potential sources of VOC are fresh paint, furniture, cleaning agents, fire suppression coatings and other solvents (ASHRAE, 2009). From on-site observations, there are no office equipment within the vicinity of sampling points. However, these locations are closed and isolated without air-conditioning subsequent to decontamination, which results in poor ventilation. Improved ventilation by introducing fresh air will reduce the level of TVOCs. The repeated measurements are taken a few days later and the results are found to be below compliance limit (Table 5.6).

Table 5.6: Repeated measurements for TVOC concentration for failed locations

LOCATION		Measuring Locations	TVOC Concentration (ppm)	Compliance Concentration (ppm) (DOSH, 2005; ENV, 1996)
Level 1	Staff Facilities	1-3	0.0	3.0
	Mortuary	1-4	0.1	
Level 2	Physiotherapy-Public Amenities (MPA) II	2-13	0.0	
Level 4	Day Lounge	4-1	0.0	
Level 5	L5-General Care Ward-Corridor I	5-3	0.1	
	L5-General Care Ward-Corridor II	5-4	0.2	
Level 6	L6-General Care Ward-Treatment Room	6-1	0.0	
	L6-General Care Ward-Corridor I	6-3	0.5	
	L6-General Care Ward-Corridor II	6-4	0.9	
Level 8	VIP Ward-Corridor I	8-3	0.4	

5.4.1.4 Formaldehyde

Formaldehyde is a colourless, strong-smelling gas. This gas usually exists as a preservative in medical laboratories and mortuaries, particle boards, household products and plywood (ASHRAE, 2009). According to the Malaysian Code of Practice on Indoor Air Quality (DOSH, 2005) and Singapore guidelines (ENV, 1996), exposure to formaldehyde should be reduced to 0.1 ppm for 8 hours of exposure. Formaldehyde concentrations at the sampling points in the building are mostly within the threshold limit, except for points 1-17, 2-8, 4-1 and 4-2. However, re-sampling is performed a few days later after these areas are flushed by fresh air, and the results show that the concentrations of formaldehyde reduced and fulfill the requirement.

5.4.2 Evaluation of Thermal Comfort Parameters

The thermal comfort parameters are shown in Figure 5.3. The air dry-bulb temperature recorded in the building ranges between 17.5 to 27.5 ℃, whereby the lowest temperature is recorded at point 2-17 (General Radiography), and the highest temperature is recorded at point 1-7 (Main Biochemistry Laboratory). The range separation now is greater than the suggested range of 20-24 ℃ (ASHRAE, 2008).

The relative humidity (RH) readings are relatively high. The relative humidity ranges between 53.6 to 90.8 %, where in only points 1-2 and 2-10 are within a range of 30-60% RH (ASHRAE, 2008). As reported by Zuraimi and Tham (2008), the outdoor air condition in the tropic is usually hot (>32°C) and humid (>60%) throughout the year. The Singapore NEA standard (Bakhda, 2007), which serves as the local guideline for tropics, recommends 70% as the limit of allowable relative humidity for indoor air, as higher humidity may favour the growth of microbial pollutants. Most measurements do not satisfy the guidelines (ASHRAE, 2008; Bakhda, 2007). High humidity levels

indicate a problematic air cooling process, resulting in the inability of the intake air to dehumidify. Poor reheating systems may also be the cause for this problem since inadequate reheating allows the air with high humidity levels to pass through the reheat coils without significant increase in temperature. This in turn, results in the supply of air with high RH levels into the room.

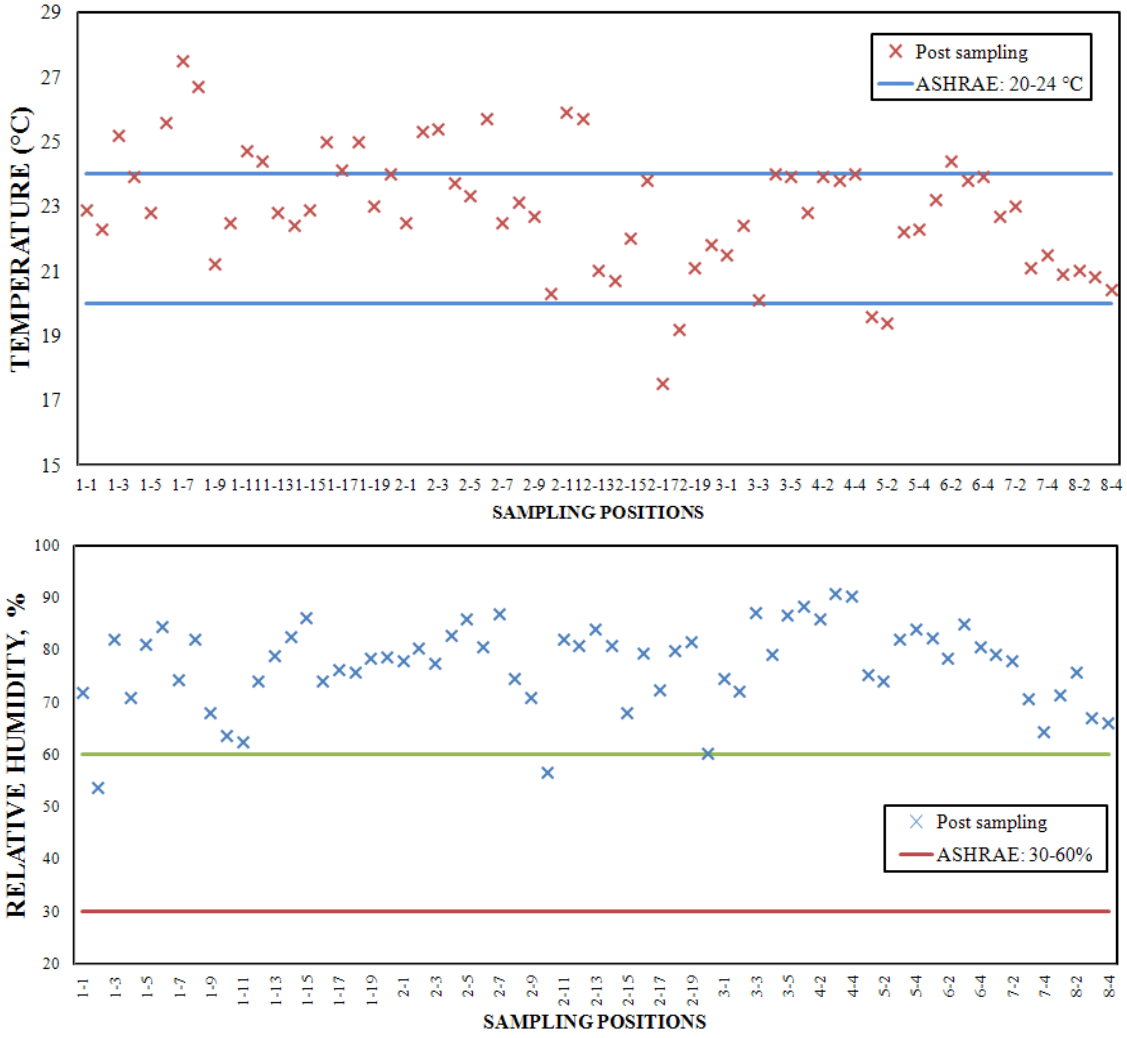


Figure 5.3: Temperature and humidity measurements

5.4.3 Evaluation of Particulate Pollution

The dust inhaled during respiration will bring hazards to the lungs. DOSH sets a requirement that the dust concentration should be kept below 0.15 mg m^{-3} (DOSH, 2005; ENV, 1996). The average concentration of indoor particulate matter ranges between 0 to 0.047 mg m^{-3} (see Figure 5.4). Hence, there are no arising issues for indoor particulate pollution.

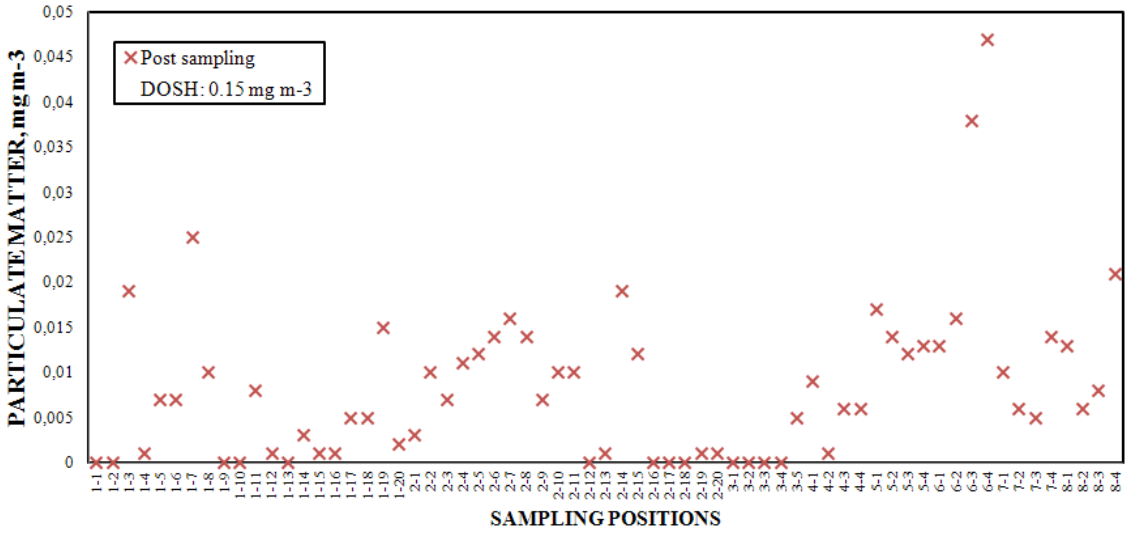


Figure 5.4: Particulate matter measurements

5.4.4 Evaluation of Microbial Pollutants

The recommended threshold level for total bacteria and fungi growth is 500 CFU m^{-3} for general areas (ENV, 1996). The air sampled throughout the building reveals that the values for total bacteria, yeast and mould count are all below the threshold value. The highest count of total bacteria, yeast and mould are 294 CFU m^{-3} and 212 CFU m^{-3}, respectively (see Figure 5.5).

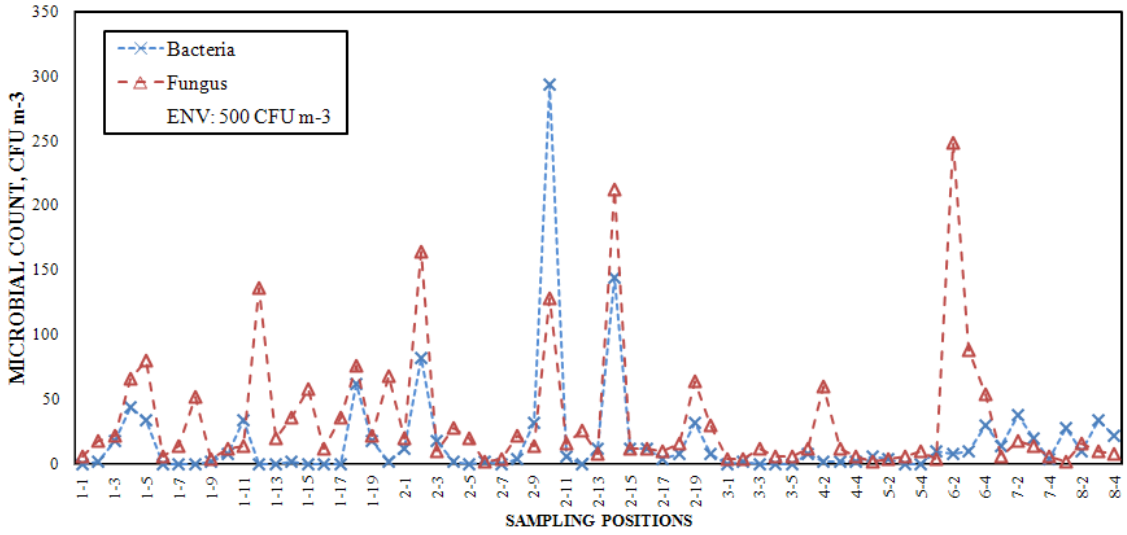


Figure 5.5: Bacteria, fungi and mould measurements

5.5 Results and Discussion: Critical Areas

The measurements for critical areas are presented in Table 5.7.

Table 5.7: Measurements for critical areas

Sampling Location Information				Thermal Comfort Parameters		Chemical Gaseous Pollutants				Particulate Pollution	Microbial Pollutants	
Department	Room	AHU	Sampling Locations	Air temperature (℃)	RH (%)	TVOC (ppm)	CO (ppm)	CO2 (ppm)	HCOH (ppm)	Particulate (mg/m^3)	BACTERIA (CFU/m^3)	FUNGI (CFU/m^3)
CCU	Cubicle 5	3-AHU-TOW-1	A1	19.2	71.0	0.2	0.0	422	0.00	0.006	8	18
	Isolation Room 1	3-FCU-TOW-1	A2	22.3	59.2	0.5	0.0	490	0.09	0.007	6	24
	Fluoroscopy	3-FCU-TOW-2	A3	21.9	74.5	9.3	0.2	389	0.05	0.010	38	58
ICU	Isolation Room 1	3-FCU-TOW-4	B1	20.6	67.3	1.2	0.0	361	0.00	0.002	52	0
	Isolation Room 2	3-FCU-TOW-5	B2	23.5	61.7	2.8	0.0	350	0.08	0.001	48	30
	in front of Bay 5	3-AHU-TOW-2	B3	17.3	75.5	0.1	0.0	304	0.00	0.006	2	12
Operating Theatre	Pre-Op Holding 2	3-AHU-OPT-1	C1	23.0	85.6	0.8	0.0	472	0.00	0.000	1	2
	Post-Anaesthesia Recovery 3	3-AHU-OPT-2	C2	22.2	86.5	0.0	0.0	385	0.00	0.001	1	9
	in front of Anaes. Work Room	3-AHU-OPT-3	C3	22.0	86.9	1.3	0.0	498	0.00	0.000	4	14
	To OT's Corridor	3-AHU-OPT-4	C4	22.6	62.0	1.8	0.0	472	0.00	0.001	3	5
	Operating Room 1 (General)	3-AHU-OT-1	C5	23.1	60.9	0.0	0.0	418	0.00	0.000	0	1
			C6	23.4	92.0	0.0	0.0	390	0.00	0.000	0	0
	Operating Room 2 (General)	3-AHU-OT-2	C7	19.5	78.3	0.1	0.0	413	0.00	0.000	0	1
			C8	23.9	98.7	0.0	0.0	338	0.00	0.000	0	0
	Operating Room 3 (Neurology)	3-AHU-OT-3	C9	23.3	97.0	0.0	0.0	444	0.00	0.000	0	0
			C10	25.7	94.7	0.0	0.0	471	0.00	0.000	0	1
	Operating Room 4 (General)	3-AHU-OT-4	C11	17.8	69.3	0.5	0.0	399	0.00	0.000	0	2
			C12	15.1	74.4	0.2	0.0	422	0.00	0.000	0	3
	Operating Room 5 (Cardiac)	3-AHU-OT-5	C13	24.1	96.7	0.0	0.0	442	0.00	0.000	0	0
			C14	24.0	97.4	0.0	0.0	414	0.00	0.000	1	0
	Operating Room 6 (Orthopaedic)	3-AHU-OT-6	C15	23.5	97.1	0.0	0.0	364	0.00	0.000	1	1
			C16	22.8	73.2	0.1	0.0	371	0.00	0.000		
Outdoors				30.3	69.5	0.0	0.0	468	0.00	0.028	10	830

5.5.1 Evaluation of Concentration of Indoor Air Pollutants

5.5.1.1 Carbon Dioxide

The chemical gaseous parameters for critical areas are presented in Figure 5.6 excluding the measurements for carbon monoxide.

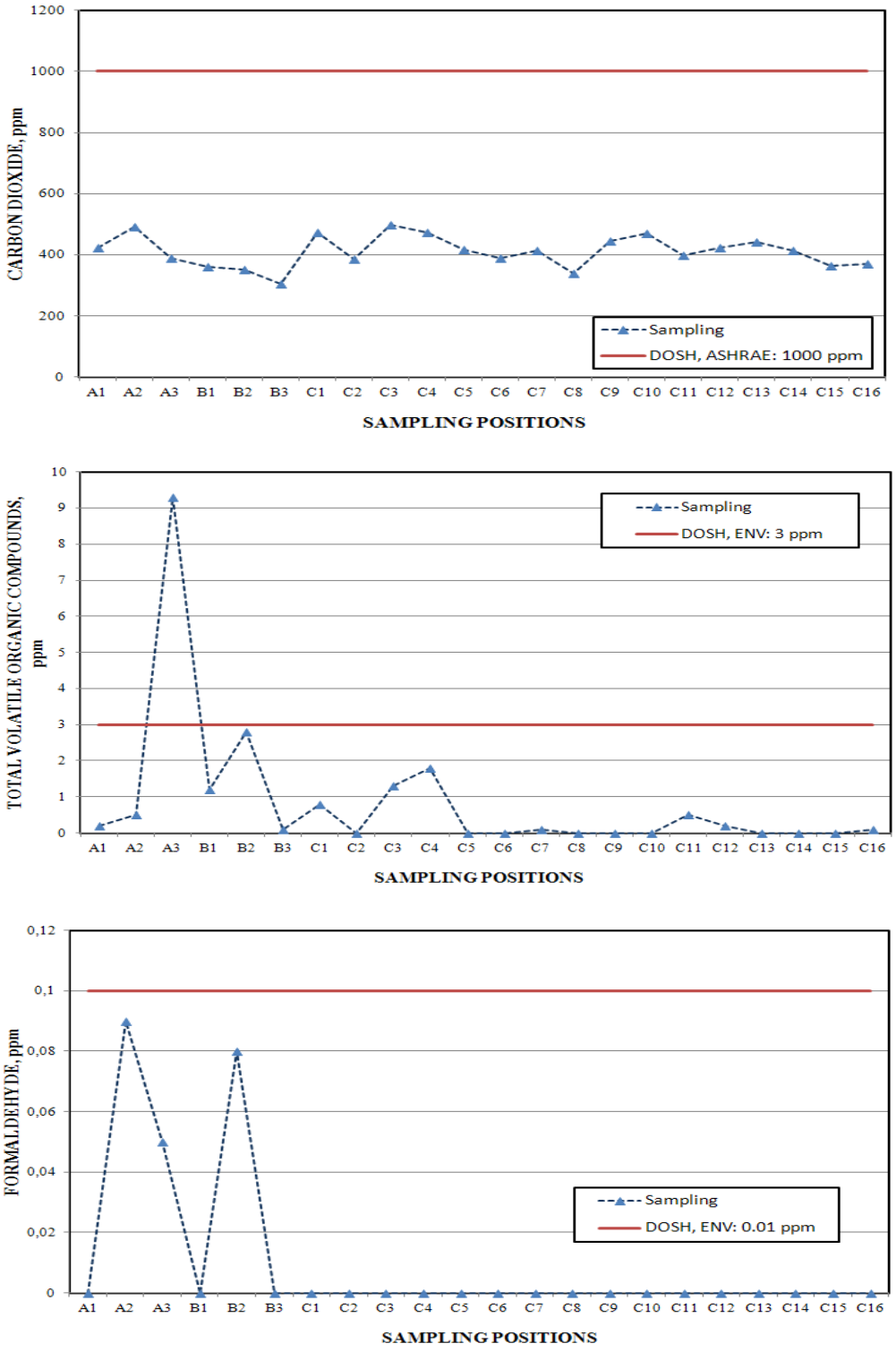


Figure 5.6: CO_2, TVOCs and HCOH measurements

The main source of carbon dioxide in critical areas is to respiration of occupants. During measurements, the sampling points consist of 4-5 people, which is similar to the number of people present in operating theatres. The concentration of carbon dioxide in these areas ranges from 304 ppm to 498 ppm. The results are well below the ASHRAE standards (ASHRAE, 2007) and Malaysian Code of Practice on Indoor Air Quality (DOSH, 2005), which recommend 1000 ppm as the maximum allowable concentration for carbon dioxide.

5.5.1.2 Carbon Monoxide

High levels of carbon monoxide can result in nausea and unconsciousness, or in extreme cases, death (ASHRAE, 2009). For safety reasons, the carbon monoxide levels should not exceed the limit of 10 ppm (DOSH, 2005) or 9 ppm (ASHRAE, 2007; ENV, 1996). The concentration of carbon monoxide ranges from 0 to 0.2 ppm, which is well below the recommended threshold limit. A carbon monoxide level of 0.2 ppm is recorded in fluoroscopy room at CCU, which may be due to the instruments operating inside.

5.5.1.3 Total Volatile Organic Compounds

Volatile organic compounds refer to the gases emitted, which cover a wide range of chemicals compounds and cause chronic diseases (ASHRAE, 2009). Concentrations of indoor VOCs are higher, due to the fact that the source of VOC is widely found indoors, which may be ten times higher concentration of VOC outdoors. Common VOC emitting materials and products are paint, photocopiers and printers in the office, building materials etc. The TVOC level should be limited below 3ppm (DOSH, 2005; ENV, 1996).

All locations are found to be within the threshold limit, with the exception of location A3 (Fluoroscopy room), exceeds the limit with a value of 9.3 ppm. Potential sources of VOC are fresh paint, furniture, cleaning agents, fire suppression coatings and other solvents (ASHRAE, 2009). From on-site observations, there are no office equipment within the vicinity of the sampling points. However, the place is closed and isolated without air-conditioning for decontamination, which results in poor ventilation. Improved ventilation can be achieved by introducing fresh air to reduce the level of TVOC. Repeated measurements are taken after all renovation works are completed and re-circulating fresh air into location A3. A value of 0.8 ppm is recorded which is within the threshold limit.

5.5.1.4 Formaldehyde

Formaldehyde is a colourless, pungent gas, which serves as a preservative in healthcare facilities such as mortuaries and medical laboratories. Glue, permanent press fabrics, paper product coatings, fibre boards, and plywood release formaldehyde (ASHRAE, 2009). Exposure to formaldehyde should be limited at 0.1 ppm for 8 hours of exposure (DOSH, 2005; ENV, 1996). The formaldehyde concentration for sampling points inside critical areas range between 0 and 0.09 ppm.

5.5.2 Evaluation of Thermal Comfort Parameters

From Figure 5.7, the air temperature recorded in CCU and ICU is within 17.3 and 23.5 ℃, whereas the value ranges between 15.1–25.7 ℃ in operating theatres as shown in Figure 5.8. These values are slightly lower than the recommended range of 20-24 ℃ for CCU/ICU, and the temperature range is greater than the suggested range of 21-24 ℃ for operating theatres (ASHRAE, 2008).

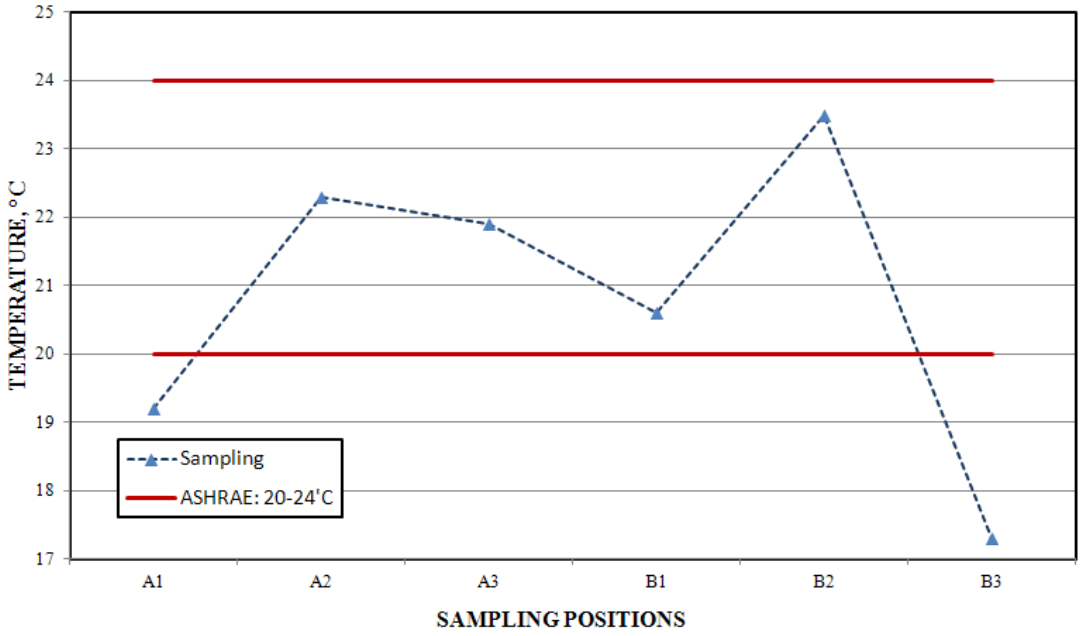


Figure 5.7: Temperature measurements for CCU and ICU

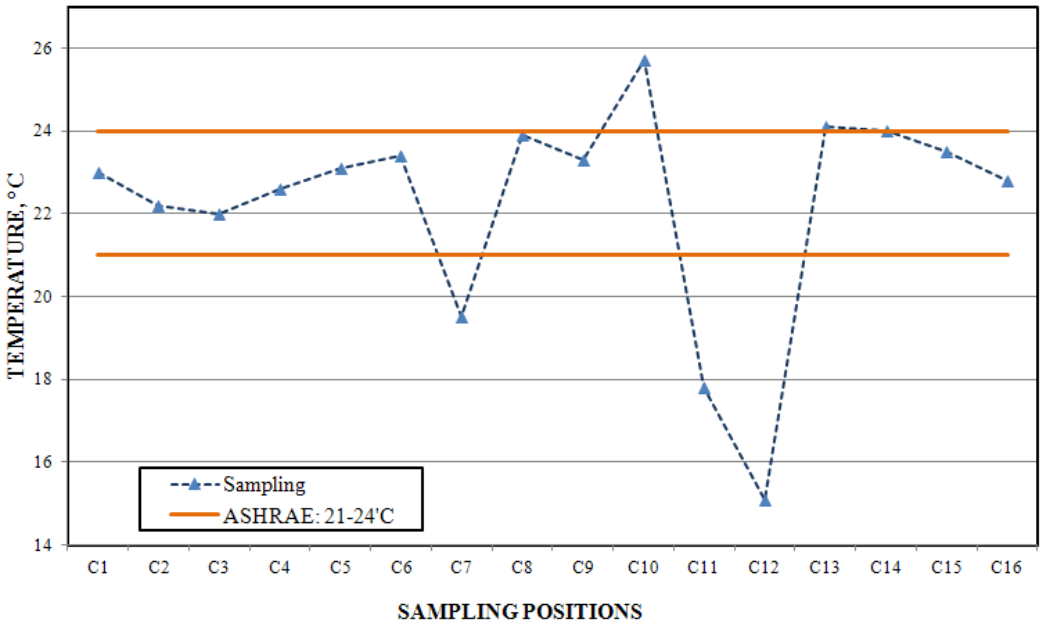


Figure 5.8: Temperature measurements for operating theatres

From Figure 5.9, the relative humidity (RH) readings measured are relatively high. The relative humidity for CCU/ICU ranges between 59.2 to 75.5 %, whereas the value ranges from 60.8 to 98.7% for operating theatres. A high RH value is recorded for nearly all locations in the critical areas, which exceeds the recommended range of 30-60% RH (ASHRAE, 2008). High humidity level indicates a problematic air cooling process, whereby the intake air is unable to dehumidify. Poor reheating systems also might be a cause for this problem since inadequate reheating allows air with high humidity levels to pass through the reheat coils without significant increase in temperature. Consequently, air with high RH is supplied into the room.

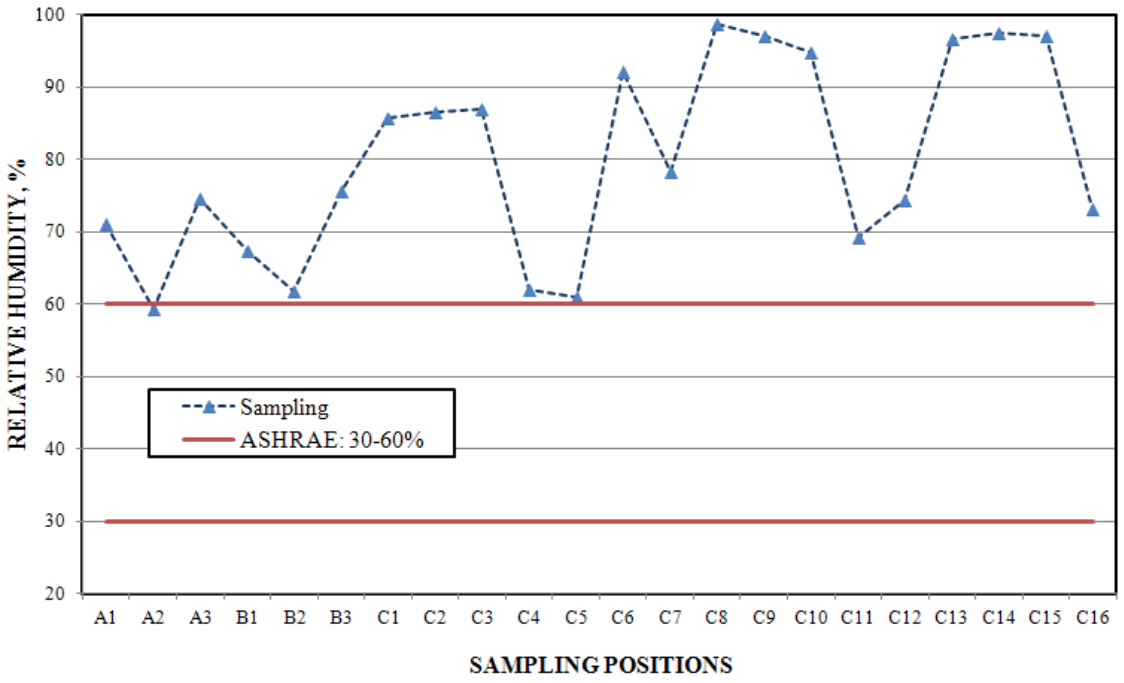


Figure 5.9: Relative humidity measurements for critical areas

5.5.3 Evaluation of particulate pollution

From Figure 5.10, the average concentration of indoor particulates range between 0 and 0.01 mg m^{-3}. Hence, it is deduced that the air is not polluted by particulate matter.

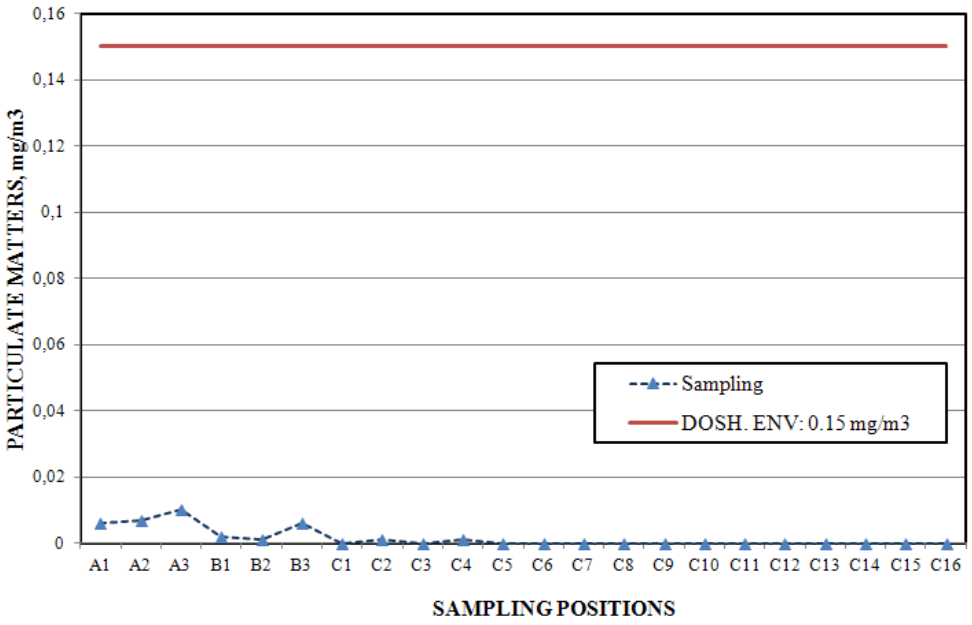


Figure 5.10: Particulate matter measurements for critical areas

5.5.4 Evaluation of Microbial Pollutants

The recommended threshold level for total bacteria and fungi growth is 500 $CFUm^{-3}$ for general areas (ENV, 1996). For conventional operation, the minimum standard for microbial air count is 35 $CFUm^{-3}$ when the theatre is empty (HTM2025, 1994b; MOH, 2010). The total count for bacteria, yeast and mould are all below the threshold value. The highest total bacteria, yeast and mould count is found to be 52 $CFUm^{-3}$ and 58 $CFUm^{-3}$, for CCU and ICU (Figure 5.11), respectively, compared to the threshold value of 500 $CFUm^{-3}$ (ENV, 1996). The highest total bacteria, yeast and mould count is obtained to be 4 $CFUm^{-3}$ and 14 $CFUm^{-3}$ (Figure 5.12), respectively, for operating theatres, compared with threshold value of 35 $CFUm^{-3}$ (HTM2025, 1994b; MOH, 2010).

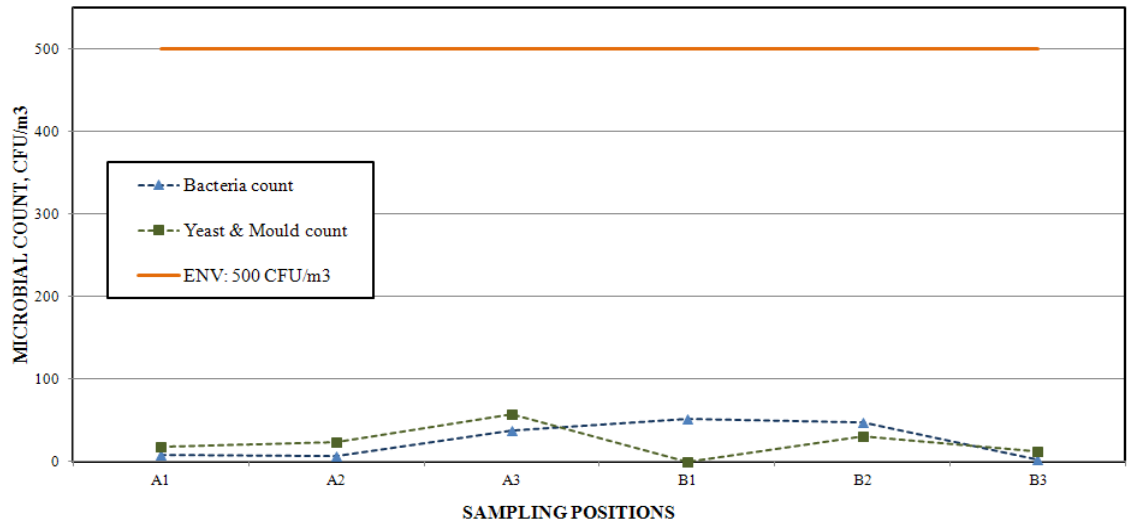


Figure 5.11: Microbial pollutant measurements for ICU and CCU

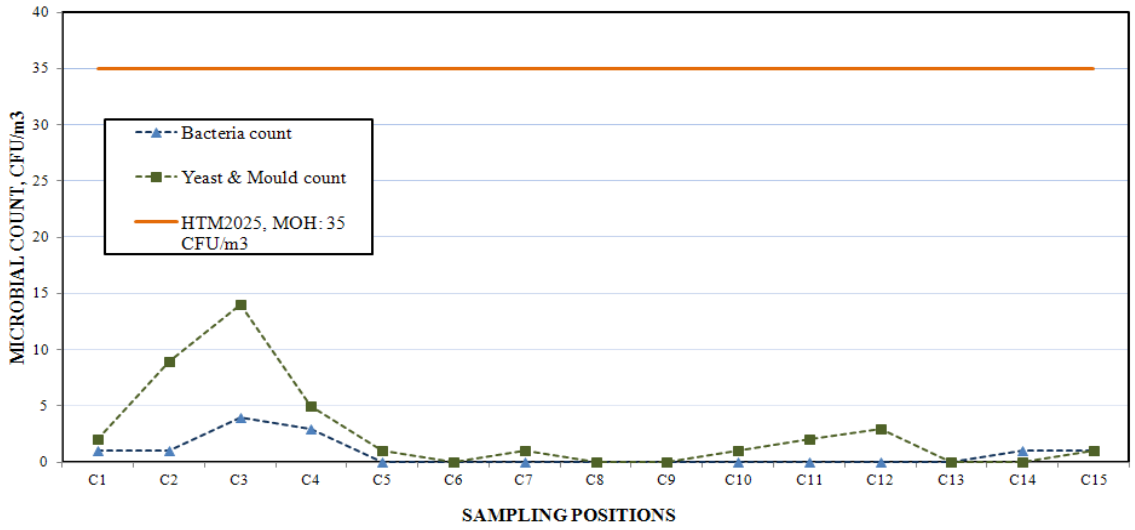


Figure 5.12: Microbial pollutant measurements for operating theatres

5.6 Recommendations

Better indoor air quality pertinently relates to higher air change rates. In common HVAC systems, the return air is re-circulated with an additional portion of outdoor fresh air (except in OT which fully requires fresh air). Hence, if the indoor air quality is found to fail in satisfying its corresponding requirements, the introduction of outdoor air is required by mainly adjusting the damper. However, the main drawback of this action is the demand for higher energy consumption since higher energy is required to treat a larger portion of outdoor air compared with the condition before amendments are made. The rationale of underlying the introduction of a higher amount of fresh air is to dilute the air inside the space, especially within an enclosed space. For high levels of chemical contaminants such as formaldehyde, it is not feasible to remove or isolate the sources since the source are fixed at a particular location. In order to dilute the air, regular purging of indoor air with outdoor air should be carried out.

The IAQ assessment alone is insufficient. In order to successfully maintain a good IAQ, continuous effort from the healthcare personnel is required by having a record on hospital associated infection (HAI). Malaysia has a total of 432 HAI case from a mission report by WHO (McLaws, 2007). Surgical Site Infection (SSI) are the highest Healthcare Associated Infection (HAI) in Malaysian hospitals in 2007, which constitute 25% of the total percentage of HAI in Malaysia. Remedial actions should be taken once a HAI is detected, followed by re-audit for post rectification as confirmation. Renovations and construction works in hospitals can increase the risk of nosocomial infections. There will be infections if there are inadequate barriers which permit the passage of airborne pollutants during renovation. In this context, renovations and construction works pertain to new (1) ACMV systems installed, (2) coat of paint applied on ceiling or walls, (3) carpet or flooring materials and furniture used and (4)

machines or equipment that are known to release chemical.

Thus, renovations and construction should be kept to a minimum. IAQ needs to be assessed if there are major renovation (Carter and Barr, 1997). To date, this healthcare facility is surrounded by forests and plantations. However, it cannot be anticipated or predicted what the development of these places is in the future. Hence, when there is heavy construction or major development in these areas, measures should to be taken with regard to the primary and secondary filters. The filters should be inspected regularly due to the possibility that fresh air is more polluted.

5.7 Summary

Indoor air quality assessment, in a large mechanical ventilated healthcare building, is presented in this chapter. Measurements of indoor environmental parameters, CO_2, CO, HCOH, TVOCs and microbial pollutants are performed, along with temperature and relative humidity inside the building. In general, ventilation with sufficient fresh air will reduce indoor environmental parameters inside the commission building to acceptable levels. The indoor temperature at most locations is within the recommended range. High humidity levels inside the building are a concern, which reveals that humidity control is a main design criteria for buildings in tropical climates.

Chapter 6: Chapter 5 covers the study of IAQ characteristics in a hospital with centralized air-conditioning mechanical ventilation system. Chapter 6 will discuss a study carried out for two types of ACMV systems, namely, centralized and non-centralized ACMV, to investigate their IAQ and thermal comfort characteristics.

CHAPTER 6

IAQ STUDY IN FOUR MALAYSIAN HOSPITALS: CENTRALIZED AND NON-CENTRALIZED ACMV SYSTEMS

6.0 Abstract

This chapter presents the study of the Indoor Air Quality (IAQ) in hospitals located in Malaysia. Field surveys are carried out to study the variations of indoor environments in different hospitals. The Study focuses on hospitals with centralized and non-centralized air-conditioning mechanical ventilation (ACMV) systems. This study consists of the analysis of thermal comfort parameters, chemical gaseous contaminants, which include carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde (HCOH) and total volatile organic compounds (TVOCs). In addition, questionnaires are completed by 109 staff to provide a subjective assessment of IAQ.

The results reveal that, non-centralized air-conditioning mechanical ACMV systems generally provide better thermal comfort for Malaysian occupants compared with centralized AC systems, due to the air movement. Centralized ACMV systems, on the other hand, provides better performance with regards to IAQ and temperature control. Centralized ACMV systems in the tropics offer a high possibility for energy savings by thermal comfort control since occupant in tropical climates prefer higher temperature and more humid environment.

6.1 Overview

Air-conditioning has been used in many parts of the world, especially in hot and humid climates for thermal comfort and humidity control in order to provide occupants with a comfortable environment. Hospital and healthcare facilities form one of crucial

buildings in a nation, which require proper air-conditioning to provide better indoor air quality for patients and staffs.

Hospital staff spend most of their time in the workplace rather than home, which subjects to long-term exposure to indoor air. Malaysia has a hot and humid climate, and therefore, most hospitals are equipped with air-conditioning systems, either centralized or non-centralized air-conditioning mechanical ventilation systems. Mechanically ventilated indoor air does not guarantee that the building is "healthy". Studies carried by Harrison e*t al*. (1987) showed that mechanical ventilation buildings receive more health complaints compared with naturally ventilated buildings. Mendell and Simth (1990) examined the symptoms in office workers in naturally ventilated buildings and air-conditioned offices, and obtained similar findings. Other studies also showed that ACMV systems in buildings are largely related to the Sick Building Syndrome (SBS) (Helsing *et al.*, 1989; Jaakkola and Miettinen, 1995; Jaakkola *et al.*, 1991; Sundell *et al.*, 1994), which significantly influences occupants' health and productivity. Graudenz *et al.* (2005) also suggested that indoor air-related respiratory symptoms are a matter of concern for places with hot and humid climates.

Poor indoor air quality will result in health problems of individual, which lead to the increase incident of health related symptoms. Occupants with SBS will experienced these symptoms, namely, nasal, eye, and mucous membrane symptoms with lethargy, dry skin, and headaches (Finnegan *et al.*, 1984). These problems may originate from many sources, where improper ventilation design or poor maintenance is believed to be one of it (Bourbeau *et al.*, 1997). Poor maintenance may encourage the accumulation and growth of indoor contaminants (e.g. bacteria and fungi) within the building indoor environment. Therefore, mode of building ventilation and maintenance will influence

the building “health”.

Research at Thailand, located in the tropical zone, shows that split-type air conditioners have the potential for good human thermal comfort control (Sookchaiya *et al.,* 2010). This offers an opportunity for non-develop countries go for lower cost ventilation system. This study is to investigate the indoor air pollutants and thermal comfort, in accordance to the audit developed by Cheong and Lau (2003) in four Malaysian hospitals with different ventilation systems.

6.2 Research Methodology

The study follows a systematic approach, as shown in Figure 6.1.

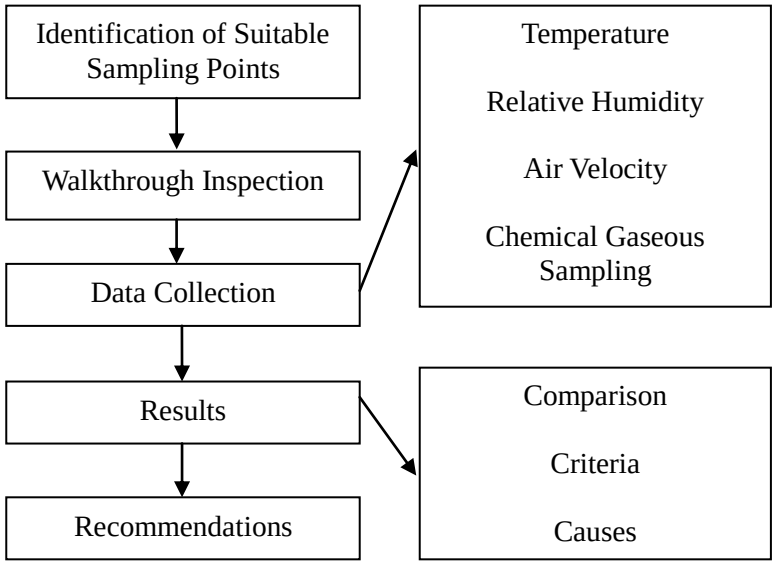


Figure 6.1: Methodology for IAQ study

6.2.1 Preliminary Stage

The IAQ study begins with a discussion amongst members of the facility management team who are responsible for the daily operation and maintenance of air-conditioning and mechanical ventilation (ACMV) systems in the building. Background of the building, ACMV systems and the feedback from occupants facilitate

by the IAQ auditor to obtain a better understanding on the status for the facilities in the building and identify possible issues faced by occupants.

This stage proceeds with a walkthrough of the premises to observe for any apparent or potential pollutant sources, occupants' activities and location of fresh air intake and exhaust. After acquiring all related information, the IAQ auditor identifies locations inside the premises where require IAQ audit, as well as identify the quantity and locations of the sampling points.

Four hospitals are selected for this study (see Table 6.1). These hospitals are chosen based on two criteria, i.e. the age of the hospital and their ventilation systems. The selected hospitals are listed as follows:

- Banting Hospital - A public hospital with a building age of 24 years. There are 11 locations involved in the study.
- Kuala Kubu Hospital - An old public hospital with a building age of 75 years. There are 8 locations involved in the study.
- Sungai buloh Hospital - A new public hospital with a building age of 12 years. There are 16 locations involved in the study.
- Selayang Hospital - A new public hospital with a building age of 12 years. There are 12 locations involved in the study.

A total of 109 occupants are involved in the study from the four selected hospitals.

Table 6.1: Summary of the hospital specification

Specification	Hospitals			
	Banting (A)	Kuala Kubu (B)	Sungai Buloh (C)	Selayang (D)
Age of hospital	Since 1975	Since 1936	Since 1999	Since 1999
Location (State)	Selangor	Selangor	Selangor	Selangor
No. of beds	151	150	620	960
No. of staff interviewed	12	37	36	24
Gender of staffs interviewed	4 males and 8 females	8 males and 29 females	6 males and 30 females	9 males and 15 females

6.2.2 Objective Measurements

In this study, the objective measurements include monitoring chemical contaminants, such as carbon monoxide (CO), carbon dioxide (CO_2), total volatile organic compounds (TVOC) and formaldehyde (HCHO) and thermal comfort parameters, i.e. air velocity, air temperature and relative humidity. These measurements are performed at several locations in each hospital to guarantee a good representation of the condition of human exposure to thermal comfort and indoor air quality.

(See Appendix D for measuring equipment)

6.2.2.1 Sampling Point Locations

The locations of sampling points in four hospitals are tabulated in Tables 6.2 and 6.3.

Table 6.2: Area of study and measurement points for non-centralized ACMV systems

ACMV System	Hospital	Department	Sampling Point
Non-Centralized Air-Conditioning Mechanical Ventilation System	Banting (A)	Microbiology Lab	A1
		Donation Blood Room	A2
		Pathology Chemistry Room	A3
		Pathology Dispensary	A4
		Pathology Waiting Area	A5
		Pharmacy Dispensary	A6
		Pharmacy Store	A7
		Pediatric 1	A8
		Pediatric 2	A9
		X-ray 1	A10
		X-ray 2	A11
	Kuala Kubu (B)	Maternity ward 1	B1
		Maternity ward 2	B2
		Hematology Lab	B3
		Pharmacy	B4
		Medical ward	B5
		Pediatric ward	B6
		Hemeodialisis room	B7
		X-ray	B8

Table 6.3: Area of study and measurement points for centralized ACMV systems

ACMV System	Hospital	Department	Sampling Point
Centralized Air-Conditioning Mechanical Ventilation System	Sungai Buloh (C)	Internal Pediatric	C1
		External Pediatric	C2
		Optalmology 1	C3
		Optalmology 2	C4
		Medical ward 1	C5
		Medical ward 2	C6
		Pharmacy 1	C7
		Pharmacy 2	C8
		Pathology 1	C9
		Pathology 2	C10
		Pathology 3	C11
		X-ray 1	C12
		X-ray 2	C13
		X-ray 3	C14
		Maternity ward 1	C15
		Maternity ward 2	C16
	Selayang (D)	Pathology 1	D1
		Pathology 1	D2
		Microbiology lab	D3
		IVU	D4
		Maternity ward 1	D5
		Maternity ward 2	D6
		Pharmacy 1	D7
		Pharmacy 2	D8
		Internal Pediatric	D9
		External Pediatric	D10
		CT Scan	D11
		MRI	D12

6.2.2.2 Chemical Gaseous Contaminants

Chemical measurements of CO, CO_2, HCOH and TVOC are carried out at 47 indoor points. These points are measured by ALNOR Indoor Air Quality (model CF930) for CO and CO_2, Portable VOC Monitor (model PGM-7600) for TVOC and Htv-M Formaldemeter for HCOH.

6.2.2.3 Thermal Comfort Measurements

Alnor Thermo-Anemometer (model 440-A) is used to measure the indoor environment thermal comfort parameters.This is a portable devices used to measured temperature, air velocity and relative humidity.

6.2.3 Subjective Assessment

In subjective assessments, a questionnaire survey is conducted in the four hospitals. The questionnaire is divided into sections with reference to the ASHRAE standard (ASHRAE, 2004). (See Appendix E)

Questionnaires are used to gather information from the respondents inside the buildings. This information is used to evaluate the buildings' health as well as for further analysis in order to develop adaptive model or suitable comfort temperature. Predicted thermal comfort temperature can be estimated from the six parameters measured using Fanger's model (Lin and Deng, 2008), with four physical variables and two personal variables. The Occupant's clothing and activity level are the personal variables that influence the occupant's thermal comfort. The actual mean vote (AMV) of thermal comfort can be determined from the occupant's response on indoor environment, using a seven-scale vote. AMV can be utilized to estimate the occupant's thermal comfort temperature (Nicol *et al.*, 1994). Sick Building Syndrome (SBS) is influenced by multiple factors, from chemical and biological that can be measured physically, and psychological that may be due to building's indoor conditions such as lighting, noise control and cleanliness (Baker, 1989). The occupant's physical background, symptoms acquired after exposure to building's environment, and building's indoor conditions are documented from the questionnaires.

6.2.4 Theory Relevant to the Present Research

Nicol *et al.* (1994) used Equation (2.5) to estimate the comfort indoor temperature, T_c. The slope a^* is the slope or regression coeficient derived by Fanger (1970) in his climate chamber experiments, having a value of 0.33. By using the vote index number assigned to each thermal comfort level and the staff's vote result, the mean thermal

sensation vote for both units, C_m (mean comfort vote) can be calculated using equation (2.4).

$$\text{Mean Thermal Sensation}, C_m = \frac{\sum_{i=Cold}^{Hot}[\text{No. of Vote for sensation i} \times \text{sensation i index}]}{Total\ Vote} \quad \text{---- (2.4)}$$

$$Comfort\ temperature, T_C = T_{gm} + \frac{4 - C_m}{a*} \quad \text{----------(2.5)}$$

6.3 Results and Discussion

6.3.1 Evaluation of Chemical Pollutants

The measured data shown in the graphs (Figures 6.2 through 6.5) represent the average values of chemical pollutants for each sampling location shown in Tables 6.2 and 6.3. Detailed data are shown in Appendix J.

6.3.1.1 Carbon Monoxide

Figure 6.2 shows CO measurements in four hospitals. The recommended exposure for CO should kept below the threshold limit of 9 ppm based on the ASHRAE standard (ASHRAE, 2007a) or 10 ppm, as indicated by the Malaysian Code of Practice (DOSH, 2005). All measurements for the four hospitals are well within the thresholds limit, whereby the CO concentrations for Hospital A, B, C and D range between 0 to 1.28 ppm, 2.5 to 3.7 ppm, 0 to 0.76 ppm and 0 to 0.37 ppm, respectively. Hospital B exhibits the highest CO level amongst the four hospitals, which may be due to insufficient ventilation of fresh air circulating the workspace. The CO level for hospitals A and B is relatively higher compared with hospitals C and D. Ventilation for centralized ACMV systems in hospitals C and D provide relatively good air distribution over the air-conditioned space compared with split-type air-conditioners and fans. The CO concentration in hospitals should be minimum or none, as smoking is prohibited in

hospitals. The contributor for carbon monoxide at hospital B may be due to indoor appliances such as hot water heaters and other combustion appliances (ASHRAE, 2009b).

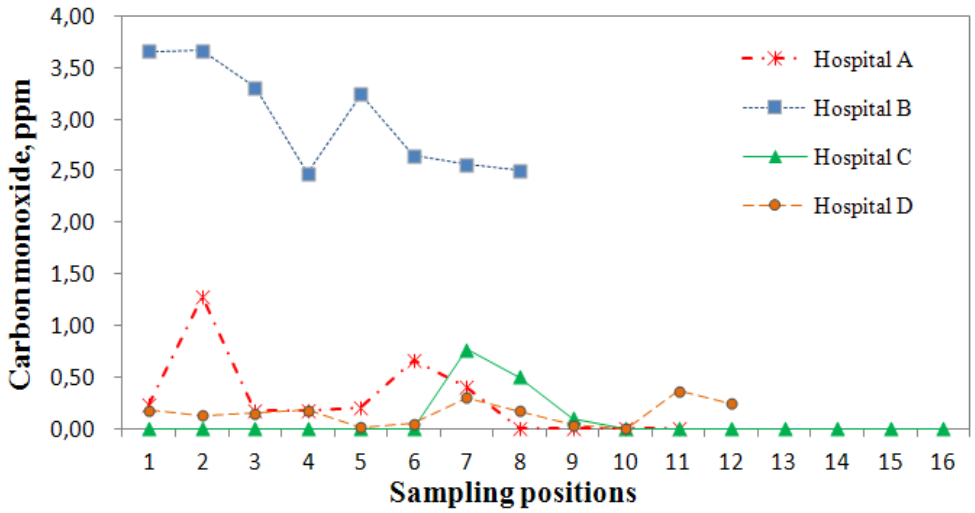


Figure 6.2: Carbon monoxide measurements in four hospitals

6.3.1.2 Carbon Dioxide

Figure 6.3 shows CO_2 measurements in four hospitals. CO_2 vary; However, the values are within the threshold limit of 1000 ppm for all four hospitals according to the Malaysian Code of Practice (DOSH, 2005) and ASHRAE standard (ASHRAE, 2007a), except for point B2. Measurements of CO_2 for hospitals A through D range between 343-785 ppm, 624-1013 ppm, 321-736 ppm and 435-828 ppm, respectively. Point B2 in Hospital B is an old maternity ward, equipped with fans. An average concentration of about 1013 ppm is recorded for this point. The high value of CO_2 recorded at this point may be due to insufficient fresh air circulating over the space. Hospital B is an old hospital building being in service since 1936, whereby most of the building ventilation is provided by fans. Split air-conditioning ventilation units located at different locations require good temperature and humidity control such as pharmacy, x-ray and hematology department. This may be the reason why the average carbon dioxide levels are still

significantly higher than the average level of other hospitals. CO_2 concentrations are often used as an overall indicator of the efficacy of ventilation system. High CO_2 (above 800 ppm) indicate inadequate fresh air exchange, especially for area with high occupancy density.

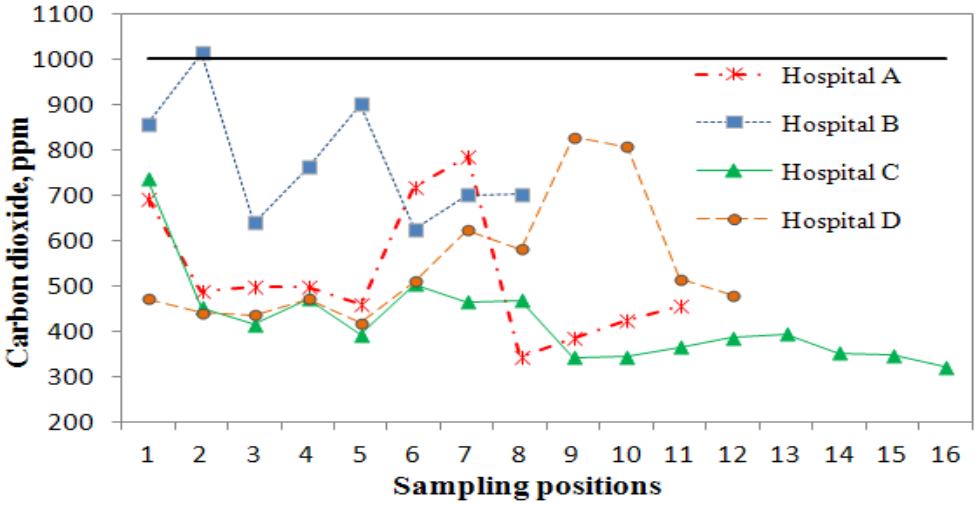


Figure 6.3: Carbon dioxide measurements in four hospitals

6.3.1.3 Total Volatile Organic Compounds

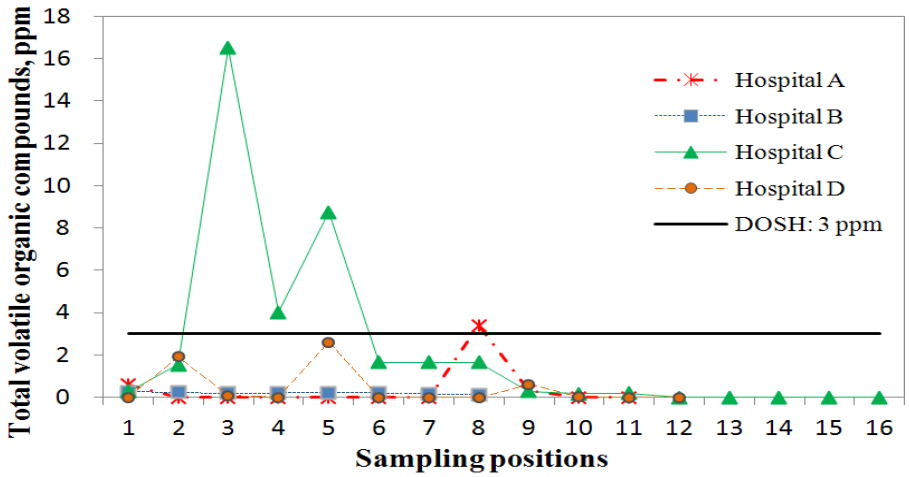


Figure 6.4: Total volatile organic compound measurements in four hospitals

Figure 6.4 shows TVOC measurements in four hospitals. There is no general agreement on the threshold values for TVOC. However, a recommended limit for acceptable indoor air quality is 3 ppm (DOSH, 2005; ENV, 1996). It is observed that the

TVOC concentration at various locations is generally below 3 ppm, except for points C3, C4, C5 and A8. This is attributed to the paint used in renovation works at hospital C and the use of volatile agents during room and corridor cleaning in the ward for hospital A.

Control studies exhibit that VOC related to SBS symptoms which reduce performance in susceptible individuals (Mølhave *et al.*, 1986). Table 6.4 show human irritation responses to TVOC mixtures. Occupants suffer from headaches due to exposure to TVOC concentration, which is verified from the total number of occupants experiencing his symptom shown in the questionnaires (see Appendix L)

Table 6.4: Human irritation responses to TVOC mixtures

Concentration (mg/m^3)	**Health Effects**	**Exposure Definition**
<0.20	No irritation	Comfort
0.20 - 3.0	Irritation and discomfort	Multifactorial exposure range
3.0 - 25	Exposure effect and headache	Discomfort
>25	Additional neurotoxic effects	Toxic

6.3.1.4 Formaldehyde (HCOH)

The formaldehyde concentration varies; however, the values are within the threshold limit of 0.1 ppm for all four hospitals, according to the Malaysian Code of Practice (DOSH, 2005) and Singapore guideline (ENV, 1996). Measurements at hospital B reveal a higher level of formaldehyde compared with other hospitals. Hospital B is an old hospital which contains many wood materials such as building structures and furniture. As mentioned at section 6.3.1.2, hospital B has insufficient fresh air circulating over the workspace. Formaldehyde is an agent commonly found inside disinfectants and medicines. Ward space requires sufficient fresh air to dilute pollutants to a safe level. Another possible reason is the high relative humidity and high temperatures that allow more vapourization of formaldehyde from wood materials (Wolkoff and KjÃrgaard, 2007).

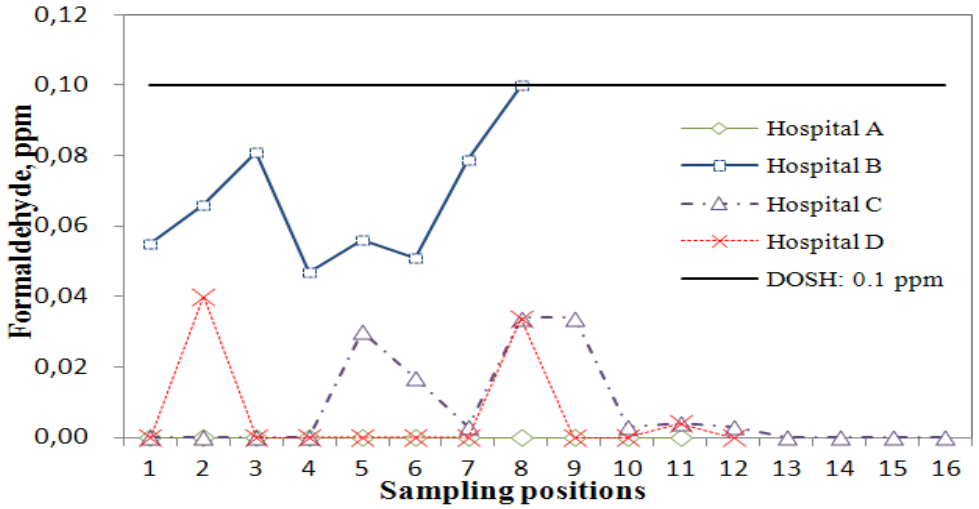


Figure 6.5: Formaldehyde measurements in four hospitals

6.3.2 Evaluation of Thermal Comfort

The thermal comfort parameters (temperature and relative humidity) are presented in Figures 6.6 and 6.7. According to ASHRAE Standard 170 (Table 6.5), the suitable air temperature for hospitals is 20-24 ℃, whereas the relative humidity should be within the range of 30-60% (ASHRAE, 2008).

Table 6.5: Design indoor condition according to ASHRAE Standard 170 (ASHRAE, 2008)

Function of Space	Pressure Relationship to Adjacent Areas	Relative Humidity (%)	Design Temperature (℃)
Class B and C Operating Room	Positive	30 – 60	20 – 24
Operating/Surgical Cystoscopic Rooms	Positive	30 – 60	20 – 24
Delivery Room (Caesarean)	Positive	30 – 60	20 – 24
Substerile Service Area	N/R	N/R	N/R
Recovery Room	N/R	30 – 60	21 – 24
Critical and Intensive Care	Positive	30 – 60	21 – 24
Wound Intensive Care (Burn Unit)	Positive	40 – 60	21 – 24
Newborn Intensive Care	Positive	30 – 60	21 – 24
Treatment Room	N/R	30 – 60	21 – 24
Trauma Room (Crisis or Shock)	Positive	30 – 60	21 – 24
Medical/Anesthesia Gas Storage	Negative	N/R	N/R
Laser Eye Room	Positive	30 – 60	21 – 24
ER Waiting Rooms	Negative	Max. 65	21 – 24

The air dry-bulb temperature recorded at Appendix L shows that the temperature

ranges between 20.5 and 32.1 ℃ for hospital A, 24.5 and 32.1 ℃ for hospital B, 19.8 and 24.8 ℃ for hospital C, 22.0 and 26.7 ℃ for hospital D. It can be observed that hospitals A and B deviate greatly from the recommended range of 20-24 ℃, whereas hospitals C and D deviate slightly from the range (ASHRAE, 2008). Hospital B is an old hospital, in which most spaces are equipped with fans to provide ventilation, and split unit air-conditioning systems are only located only in vital locations such as pharmacy, hematology lab and pharmacy. The average temperature in hospitals A and B is higher than that in hospitals C and D, which is close to the range of 20-24 ℃.

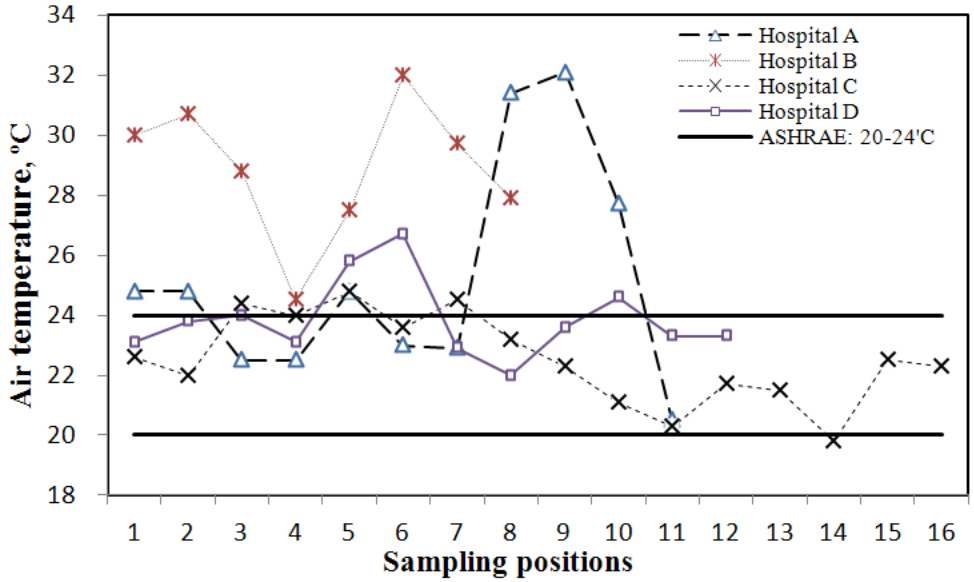


Figure 6.6: Air temperatures measurements in four hospitals

The ASHRAE thermal sensation scale developed from previous studies (Rohles, 1973; Rohles and Nevins, 1971) is used in this assessment to identify the thermal comfort conditions for the occupants in each hospital. The comfort votes are recorded as a number between 1 (cold) and 7 (hot) which equals to -3 and 3 from the ASHRAE thermal sensation scale. 4 (1 to 7 scale) or 0 (-3 to 3 scale) represent neutral point or mean preference vote, in which occupants are satisfied with the internal temperature. The comfort temperature shown in Table 6.6 was calculated using Equation (2.5) (Nicol *et al.*, 1994).

Table 6.6: Thermal sensation poll in four hospitals

Hospital	Mean thermal sensation		Average Indoor Temperature (℃)	Comfort Temperature (℃)
	1 to7 scale	-3 to 3 scale		
Banting (A)	3.417	-0.297	25.2	26.95
Kuala Kubu (B)	3.703	-0.583	28.9	29.79
Sungai Buloh (C)	1.940	-2.050	22.5	28.74
Selayang (D)	1.688	-2.313	23.9	30.86

The comfort votes display a bias towards the cool side of the scale (Figure 6.7). From 109 votes, the cool side of the scale accounts for 70% and the warm side accounts for 5.5%. This analysis reveal that the occupants generally prefer a higher temperature of around 27–31 ℃, which is higher than the recommended AHSRAE standard of 20-24 ℃ (ASHRAE, 2008). This result is consistent with the study of Yau and Chew (2009), which followed on the thermal comfort of hospital workers in Malaysia, which also suggested a higher comfort temperature.

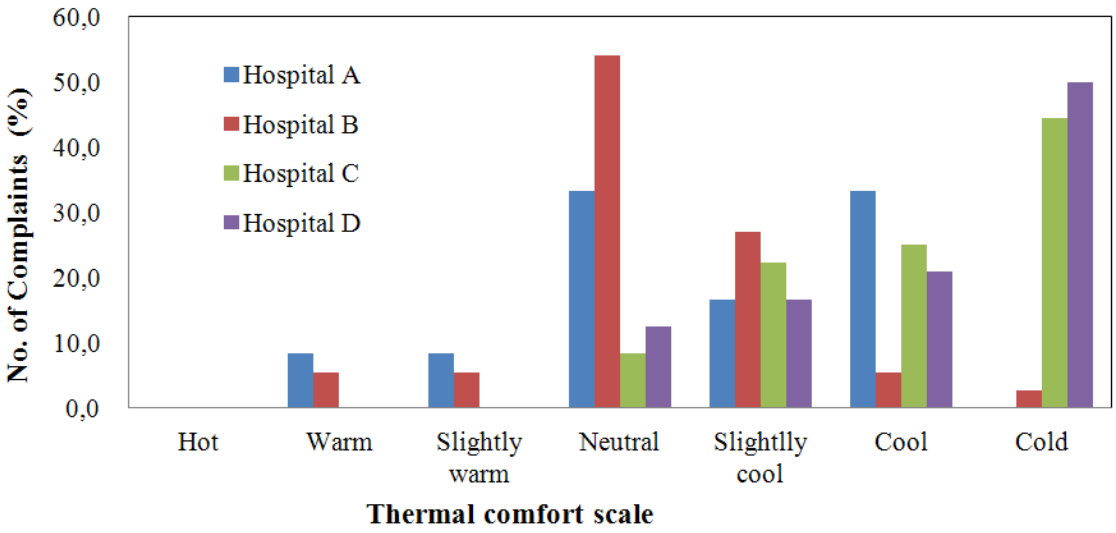


Figure 6.7: Distribution of occupant response on thermal sensation

The relative humidity in all hospitals exceed the recommended value of 60% (ASHRAE, 2008), except for hospital B. The relative humidity tabulated in Figure 6.8 shows that the relative humidity ranges between 56.9-72.6% (Hospital A), 52.6-59.9% (Hospital B), 62.9-77.9% (Hospital C) and 52.9-67.8% (Hospital D). The relative

humidity for hospitals A, B and D are within or approximate the recommended value of 60%. However, Hospital C has a relative humidity value which greatly deviates from the recommended value.

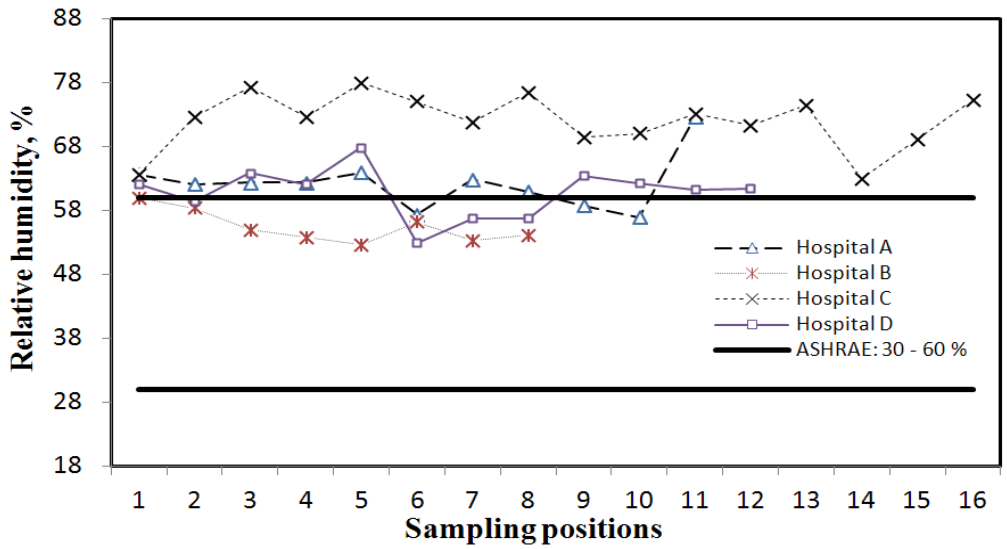


Figure 6.8: Relative humidity measurements in four hospitals

6.3.3 Subjective Assessment: Questionnaire Survey

For subjective assessment, a total number of 109 questionnaires are completed by the staff from four hospitals. A total number of 49 questionnaires are collected from Hospitals A and B, whereas 60 questionnaires are gathered from Hospitals C and D. Figure 6.9 shows the results of the survey, with regards to staff complaints on physiological parameters.

Dry symptoms (dry eyes, dry or irritated throats, and skin dryness, rash or itch) appear to be the most common complaint amongst the respondents, followed by headaches, noise irritation and sleepiness, as well as other complaints, as shown in Figure 6.9 and Table 6.7.

Table 6.7: Staff complaints on physiological parameters

Hospital	Dry eyes	Dry or irritated throats	Skin dryness, rash or itch	Headaches	Noise Irritation	Sleepiness	Difficulty concentrating	Dizziness	Chest tightness or breathing difficulties
Hospital A	3	3	5	4	4	6	2	3	1
Hospital B	7	10	6	9	4	8	0	1	1
Hospital C	10	7	19	15	9	12	0	2	0
Hospital D	5	6	16	4	3	7	1	1	1

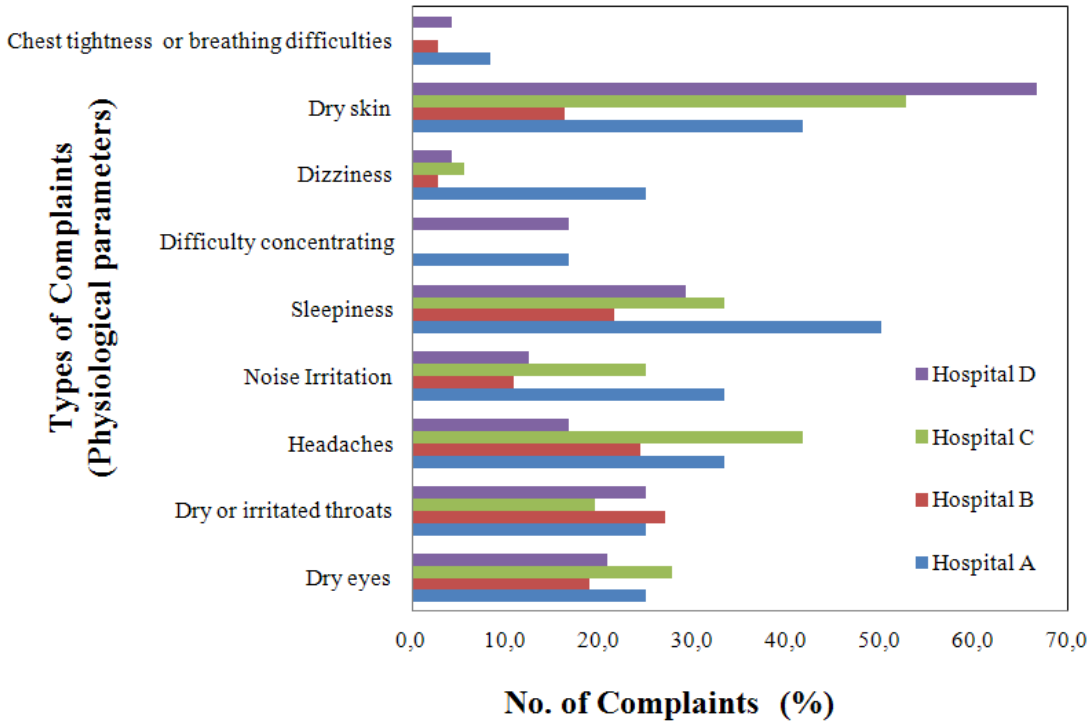


Figure 6.9: Staff complaints on physiological parameters

The staff in all departments (Table 6.8) experience some levels of skin dryness, rash and itch, which may be attributed to the long-term exposure in air-conditioned workspace. Dry eyes and dry or irritated throats are the common complaints by staff located in department whereby activity levels and air temperature are low, such as Pharmacy, Pathology and Radiology departments. These three departments require a more crucial control in humidity and temperature for equipment (Radiology), drug storage (Pharmacy) and laboratory activities (Pathology).

Table 6.8: Dry symptom complaints in Kuala Kubu and Selayang Hospitals

Kuala Kubu Hospital					
Symptoms (Air Quality Effects)	Pharmacy	Pathology	X-Ray	Pediatric	Maternity
Dry eyes	4	2	4	0	0
Dry or irritated throats	1	0	6	0	0
Skin dryness, rash or itch	1	4	9	1	4
Selayang Hospital					
Symptoms (Air Quality Effects)	Pharmacy	Pathology	X-Ray	Pediatric	Maternity
Dry eyes	3	1	1	0	0
Dry or irritated throats	3	0	3	0	0
Skin dryness, rash or itch	5	4	2	1	4

Noise irritation may be contributed by noise from ventilation systems or from other sources such as vehicles and construction activities. A few staff complained that there was excessive irritating noise in Hospital A, which is not attributed to noise from ventilation systems. Hospital A (Banting Hospital) is located along a heavy-traffic road, which results in excessive vehicle noise. Hospitals B, C and D are stand-alone buildings, which occupy a large area, away from traffic. Hence, noise irritation is mostly contributed by noise from ventilation systems and voices of occupants. Detailed data are shown in Appendix L.

Sleepiness and dizziness may be attributed to inadequate fresh air exchange, such as Hospital B with higher CO_2 levels. Sleepiness may be contributes by other factors, such as air temperature and relative humidity, induce sleepiness., Loss of heat will make humans feel sleepy with declining human body temperature (Kräuchi *et al.*, 1997).

Headache is a SBS symptom commonly faced by occupants, which may arise from stress, environmental irritations (i.e. lighting and noise), and individuals' health condition.

6.4. Summary

The results for chemical gaseous monitoring show that most of the pollutants are within the threshold limits, with the exception of total volatile organic compounds for locations A8, C3, C4 and C5. This is attributed to the paint used in renovation works at Hospital C and the use of volatile agents during room and corridor cleaning in the ward for Hospital A. Dilution can be carried out after cleaning and renovation works by regular removal of indoor air and substitution with fresh outdoor air. This can be achieved via natural ventilation, by allowing the flow of air through open windows and doors after renovation work. Mechanical ventilation can be employed to increase the ventilation rate. Generally, the fresh air condition and air change effectiveness of systems in the four hospitals are sufficient in diluting and removing pollutants, according to the recommended standards (ASHRAE, 2007a; DOSH, 2005; ENV, 1996).

Another cause of concern is the cold air, which is expressed by 61% of the respondents. In addition, the staff experiences dry symptoms although the measured air temperature is 25.1℃ and relative humidity is 77.9%. Malaysian residents are accustomed to hot (air temperature of 30℃) and humid (relative humidity of 90%) environment throughout the year. This is in agreement with comfort temperature calculated using the equation suggested by Nicol *et al.* (1994), having a range of 27-31℃. The average temperature is determined to be 29℃, which is close to the normal air temperature of 30℃. The current ACMV system design may be over-sized based on the recommended standard (ASHRAE, 2008), whereby the system heat load is unbalanced. Operating theatres and other critical areas may require low temperature and humidity due to their nature. However, energy savings can be achieved at other sections in the hospital in this region.

The overall results obtained from objective measurements and subjective assessment in this IAQ study for hospitals show the IAQ profile, thermal comfort of occupants and common complaints faced. These are carried out to analyze the performance of centralized and non-centralized ACMV systems with regards to two objectives, i.e. thermal comfort levels and gaseous pollutant control. In general, hospitals with non-centralized ACMV systems have better thermal comfort levels (Hospital A and B). However, hospitals with centralized ACMV systems have better gaseous pollutant control. More attention is required for old hospitals, such as Kuala Kubu Hospital which had been in service for 76 years. Such hospitals rely more on natural ventilation and split type ACMV systems which cannot efficiently remove indoor air pollutants unlike other hospitals. More studies should be carried out in the future to cover more hospitals and respondents to in order to gain better understanding on ACMV system and IAQ for Malaysian hospitals.

Chapter 7: Studies from Chapter 4 through 6 show that high humidity level is a matter of concern for healthcare facilities in tropical climates. Humid environment favours the growth of pollutants inside healthcare buildings. Therefore, Chapter 7 studies on the use of tea tree oil as an alternative vapour decontamination agent in healthcare facilities.

CHAPTER 7

TEA TREE OIL VAPOUR DECONTAMINATION FOR INDOOR AIR MICROBIAL POLLUTANT CONTROL

7.0 Abstract

This chapter discusses an investigation on the indoor air quality of a fully air-conditioned eight-storey healthcare facility in East Malaysia before and after vapour decontamination process. East Malaysia is located in region with hot and humid climate, which favours the growth of bacteria, yeast and mould. The main purpose of the investigation is to identify the potential usage of tea tree oil vapour decontamination to improve the indoor air quality by reducing active bacteria, yeast and mould concentrations in indoor air. 336 samples are taken inside the building for indoor air at 84 locations and 24 samples are taken for outdoor air at 12 locations, which are nearby fresh air intake of air handling units.

The results show that the humidity level remains high throughout the research, exceeding 60% relative humidity, which favours the growth of bacteria, yeast and mould. By applying vapour decontamination from air handling units to the ventilated air serving areas, the average bacteria, yeast and mould counts are successfully reduced below the recommended threshold of 500 CFU m^{-3} for normal zones and 35 CFU m^{-3} for critical zones. Decontamination shows that there is a possibility of applying tea tree oil air treatment in tropical countries such as Malaysia for indoor air quality management, especially for bacteria, yeast and mould control in healthcare facilities. Future research is needed for more effective decontamination methods with different chemical disinfectants for vapour decontamination in the tropics.

7.1 Overview

Air infectious diseases have become a concern after the spread of influenza H1N1 and severe acture respiratory syndrome (SARS) viruses. Several research done showed that air is a significant factor which contribute to the outbreak. In early 19th century, humans identified that air serves as transport medium for infectious diseases (Riley and O'Grady, 1974), which depends on relative humidity and temperature (Lowen *et al.*, 2007). Infectious diseases can be directly or indirectly spread from one person to another. Bacteria, fungi and mould are amongst the pathogenic microorganisms, which cause infectious diseases (Mims, 1976). Mould, yeast and bacteria are likely to build up in air-conditioning systems, especially when the humidity level is sufficient (Maus *et al.*, 2001). This suggests that hot and humid environments in the tropics such as Malaysia favour the growth of mould, yeast and bacteria in air-conditioning systems.

The cleanliness of space and air-conditioning systems in healthcare facilities is extremely crucial. The performance of ventilation systems, dust loading conditions as well as biological contaminants are contributing factors to air cleanliness. Most of the biological contaminants such as bacteria, mould and yeast are categorized as potential allergenic (Denning *et al.*, 2006; Gravesen, 1979). Continuous exposure to these biological contaminants leads to irritation, allergies and infection (Fung and Hughson, 2003).

Research on the relationship between air temperature and relative humidity showed that high humidity levels favour the growth of bacteria, yeast and mould, and lower temperature require more humid environments to encourage the growth (Nielsen *et al.*, 2004; Pasanen *et al.*, 1991). Malaysia is a country located with hot and humid climate. There have been issues on fungi growth inside buildings in tropical climates (Lim *et al.*,

1989).

Hospital is a facility which requires stringent precautions on infectious disease control, particularly in the design of ventilation systems in order to control the possible air contaminants. However, humidity is not the sole factor which influences the growth and spread of bacteria because bacteria such as *S. aureus* and methicilin-resistant *Staphylococcus aureus* (MRSA) can survive in dry environments for prolonged periods (Hirai, 1991; Neely and Maley, 2000; Smith *et al.*, 1996). Decontamination is therefore required to decrease the survival chances of infectious agents.

The purpose of decontamination is to eliminate or minimize the level of biological contaminants on medical devices and room surfaces. There are a few steps involved in decontamination, which comprises of cleaning, disinfecting and sterilizing. However, limited chemical disinfectants are available for air decontamination. A number of researchers carried out research regarding air decontamination in healthcare buildings in order to solve these issues, whereby hydrogen peroxide is commonly utilized as the solvent (Andersen, Rasch, Hochlin *et al.*, 2006; Davies *et al.*, 2011; Jahnke and Lauth, 1997; Johnson *et al.*, 1992; Klapes and Vesley, 1990.). European EN1276 and EN12054 standard suspension tests (Messager *et al.*, 2005) and a trial for the clearance of MRSA colonization (Dryden *et al.*, 2004) revealed that tea tree oil processes antibacterial capabilities. Hence, tea tree oil has potential to serve as an alternative agent for decontamination.

This study investigates the potential usage of tea tree oil vapour decontamination for indoor air microbial control in a newly commissioned healthcare building.

7.2 Materials and Methodology

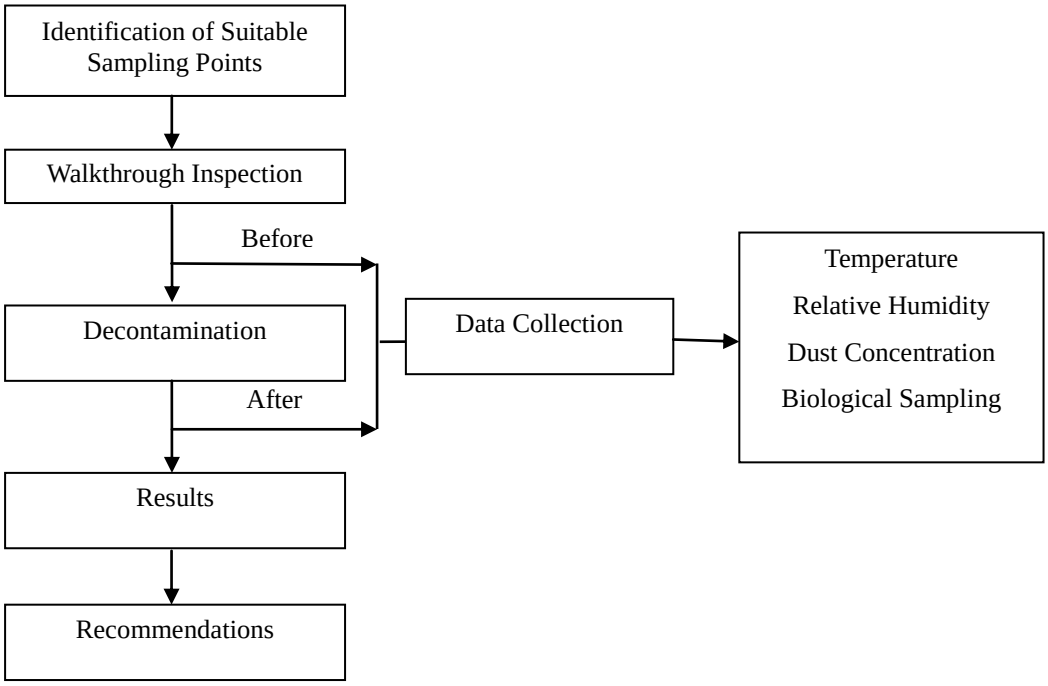


Figure 7.1: Methodology for decontamination study

Figure 7.1 show the methodology for decontamination study. Decontamination is carried out in a newly-commissioned healthcare building. The healthcare building was launched for construction in 1998 and completed in three years. This is a fully air-conditioned eight-storey building with roof level and can be categorized into critical and non-critical areas. The overall floor area of the healthcare facility is 41,450 m^2, with critical areas of about 4,553 m^2.

The building does not have a basement level, and the first storey consists of Information Technology (IT) Department, Medical Record Department, Cancer Centre, Pharmacy, Mortuary, laboratory, Materials Management and Waste Management, Laundry and Linen Service, Auditorium, and staff facilities. The second storey comprises of a cafeteria, Physiotherapy Department, Wellness and Heart Centre, Kidney and Stone Centre, Imaging Department, Accident and Emergency Department, Special

Outpatient Clinic (SOC) and general administration offices. The third storey consists of Central Sterile Supply Department, Invasive Cardiac Laboratory, Cardiac Catheterization Department and critical areas, namely, operating theatres, Coronary Care Unit and Intensive Care Unit. The fourth through eighth levels accommodate the wards.

The air-conditioning system for the building is basically a centralized chilled water system in which the chiller plant is located outside the main building. Chilled water is distributed to all air-handling units located throughout the building. Each department is served by at least one Air handling Unit (AHU). The building has a total of 72 AHUs, with 14 AHUs serving the critical areas located at Level 3 of the eight-storey building. All AHUs are installed with primary and secondary filters. Operating theatres consists of high efficiency particulate air (HEPA) filters, before the air is supplied into the working space.

Vapour decontamination is the process whereby a gas or vapour is formed from disinfectants. The selected area for decontamination is usually sealed completely during the decontamination process. The main advantage of vapour decontamination technologies is that medical equipments with internal areas which are cumbersome to clean can be disinfected with vapourized disinfectants (Andersen, Rasch, andHochlin, 2006).

In most cases, common chemical disinfectants are chosen from powerful oxidizing agents such as ozone, hydrogen peroxide and chlorine dioxide. However, such disinfectants corrode metals due to their strong oxidizing properties.

In this study, tea tree oil (*Melaleuca alternifolia*) is used as the organic disinfectant. Tea tree oil consists mostly of cyclic monoterpenes, whereby 50% are oxegenated, and another 50% are hydrocarbons (Brophy *et al.,* 1989). Studies on variety of essential oils revealed that their antimicrobial properties are attributed to the presence of active monoterpene constituents (Beylier, 1979; Knobloch *et al.*, 1988; Morris *et al.,* 1979), which exert membrane damaging effects (Sikkema *et al.,* 1995). Studies of Cox *et al.* (1998) and Gustafson *et al.* (1998) provide the evidence of lethal action related to cytoplasmic membrane damage and loss of cellular electron-dense material when exposed to tea tree oil. Further studies by Cox *et al.* (2001) showed that the antimicrobial activity of tea tree oil results from its ability to disrupt the permeability barrier of microbial membrane structures.

7.2.1 Walkthrough Inspection

A walkthrough inspection is carried out prior to sampling. The objective of the walkthrough inspection is to identify potential indoor sampling points according to AHUs serving area as well as outdoor sampling points according to the location of AHUs (DOSH, 2005). The floor plans and drawing of air-conditioning and mechanical ventilation (ACMV) systems are collected after the sampling points in the areas of interest are identified.

7.2.2 Measurements

336 and 24 samples are taken for indoor and outdoor air, respectively. The measurements are taken before and after the air decontamination process. 84 locations was sampled within the building, which can be sub-divided into 58 locations for general zones and 26 locations for critical zones. 12 sampling points are taken outdoors in close proximity to the fresh air intake of air handling units (DOSH, 2005). For post sampling

measurements, the centralized air-conditioning systems which serve relevant AHUs in the area of interest needs to be left running for at least 24 hours following the decontamination process, prior to the measurements. (Refer Appendix D for measuring equipments).

7.2.2.1 Temperature and Relative Humidity

The temperature and relative humidity of the indoor environment are measured using Alnor Thermo-Anemometer (model 440-A). This is a portable devices used to measured temperature, relative humidity and air velocity.

7.2.2.2 Particulate Matter

The concentration of suspended particulates (total dust count) is measured using TSI DuskTrakII Aerosol Monitor (Model 8532).

7.2.2.3 Biological Sampling

Biological sampling is carried out using a single stage SAS Super 100 air sampler. The medium used for bacteria collection is Plate Count Agar (PCA) whereas the media used for the collection of fungi and mould is Sabouraud Dextrose Agar (SDA). The air sampler is capable of drawing air samples at a rate of 100 litre m^{-3}, and impact to PCA and SDA petri-dishes. Sampling is performed in a region of 75-120 cm above the floor (DOSH, 2005). The volume of the air sampled varies according to the nature of air in the sampling areas. The air volume taken for operating theatres is 1000 litres while the volume for other non-critical areas is 500 litres. After sampling, the air samples are incubated under different conditions. The PCA petri-dishes are incubated at 37 ℃ for 48 hours, whereby the SDA petri-dishes are incubated at 30 ℃ for 120 hours. The microorganisms in the air samples are counted after incubation and the unit of

measurement is in colony–forming units per cubic meter (CFU m^{-3}).

7.2.3 Decontamination Procedure

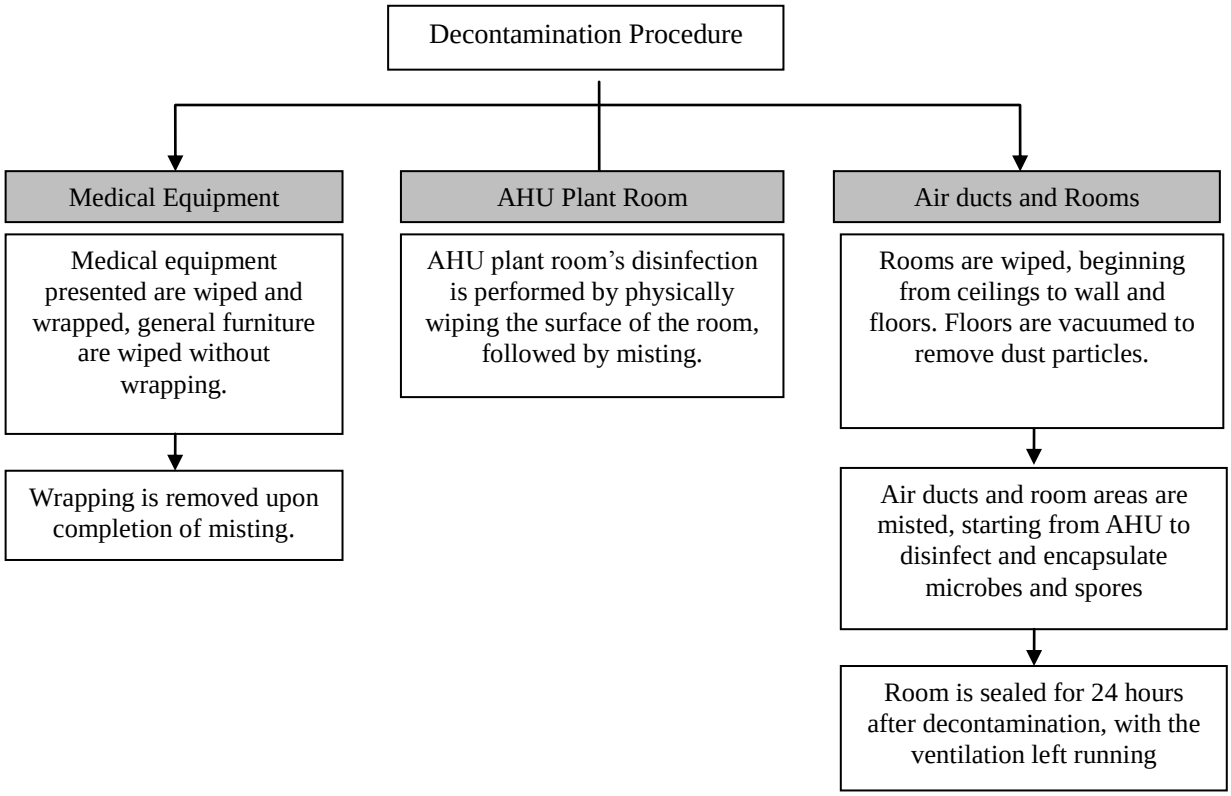


Figure 7.2: Procedure for decontamination process

7.2.3.1 Cleaning and disinfection

Figure 7.2 show the procedure for decontamination process. In this research, cleaning and disinfection of the surface are performed by wiping devices with Trigene in a ratio of 1:20. This process is implemented before the misting process. All medical and electronic devices inside the general area are disinfected and wrapped. All surfaces (floors, walls and ceiling) in the room are wiped. Floors are vacuumed to remove dust particles. For critical areas, wiping process is repeated three times.

7.2.3.2 Vapour Decontamination

Room decontamination process is divided into two categories, namely, general and critical areas. An electric fogging machine is used to convert the liquid decontamination solvent (tea tree oil) into it to mist. The mist is used for decontaminating the indoor air.

General area covers approximately 36,897 m^2 floor area. The decontamination equipment is set up in the AHU chamber, whereby the window and door leakage of the AHU serving area are sealed during the decontamination process. The mist produced at the AHU is then distributed throughout the room via ducting from the AHU into the serving general area. The AHU is left to run for 24 hours after decontamination prior to sampling.

Critical area covers approximately 4,553 m^2 floor area which comprises of operating rooms and surgical sites. Air ducts are misted from the AHU chamber. An additional decontamination step for critical area is room space misting. The room air diffusers are sealed and robotic misting is carried out inside the room to further eliminate other airborne contaminations. The diffusers are re-opened once the misting process is completed and the air-conditioners and left to run for the next 24 hours.

In this research, vapour decontamination is applied for ducting and areas served by each AHU unit. Gel Air Solution (tea tree oil) is used to control microbial contaminants such as mould, yeast and bacteria, which usually spread through air-conditioning systems.

7.3 Results and Discussion

Table 7.1: Results of microbial samplings

	Bacteria		**Fungi and mould**	
	Matched before decontamination	Matched after decontamination	Matched before decontamination	Matched after decontamination
	Outdoors			
No of points sampled	12	Null	12	Null
Average CFU/ m^3	129.1	Null	673.3	Null
	General Area			
No of points sampled	58	58	58	58
Average CFU/ m^3	120.3	18.5	70.8	34.4
	Critical Area			
No of points sampled	26	26	26	26
Average CFU/ m^3	70.1	8.2	30.8	9

Table 7.1 presents the average value for bacteria count, fungi and mould count and the number of points sampled for each area before and after the vapour decontamination process. The average yeast and mould count for outdoor environment is 673.3 CFU m^{-3}, which is above the recommended standard value of 500 CFU m^{-3} (ENV, 1996; MOH, 2010). This suggests that the outdoor air introduced into the building may be one of the factors contributing to the active yeast and mould inside the building. High levels of yeast and mould count may be attributed to humid climate, which flavours their growth. Table 7.1 indicates that the filters in the air handling units are efficient for removing yeast and mould in the air to an acceptable level.

Bacteria count however, does not reflect much variation for indoor air in general area. Indoor air is solely supplied in the critical area after passing through the HEPA filters, which indicates the removal of bacteria. The bacteria count shows that the content of bacteria for outdoor air and indoor air in general area are all below the recommended threshold. Detailed data are shown in Appendix G.

7.3.1 General Area

7.3.1.1 Evaluation of Air Temperature and Relative Humidity

The air temperature and relative humidity measurement are presented in Figure 7.3. The measurements are taken twice, i.e. before and after the decontamination process.

The air dry-bulb temperature recorded for 58 locations in the general area, ranges between 16.9 and 29.9 ℃ before decontamination, with an average temperature of 23.2 ℃. The ASHRAE standard suggests an air temperature range of 21-24 ℃ (ASHRAE, 2008), which is less than the Singapore indoor air quality guidelines (ENV, 1996). The Singapore indoor air quality guidelines are used since its climate is similar to that of Malaysia. The results deviate from the recommended range for acceptable indoor air quality of 22.5 – 25.5 ℃ for general area. Overall, 27 locations fall within the recommended range for air temperature prior to decontamination. The air dry-bulb temperature ranges from 17.5-27.5 ℃ during post decontamination, with an average of 22.9 ℃, which accounts for 37 sampling points satisfying the temperature requirement.

For both measurements, the relative humidity is significantly above the recommended range of 30-60 % RH (ASHRAE, 2008) with a value of 70.5% RH and 77.4% RH before and after decontamination, respectively. High humidity indicates a problematic air cooling process, whereby the intake air fails to dehumidify. Poor reheating system may be the cause of this problem due to the fact that inadequate reheating enable air with high humidity levels to pass through the reheat coil without any significant increase in temperature. This results in the supply of air with high humidity levels into the room. Detailed data are shown in Appendix H.

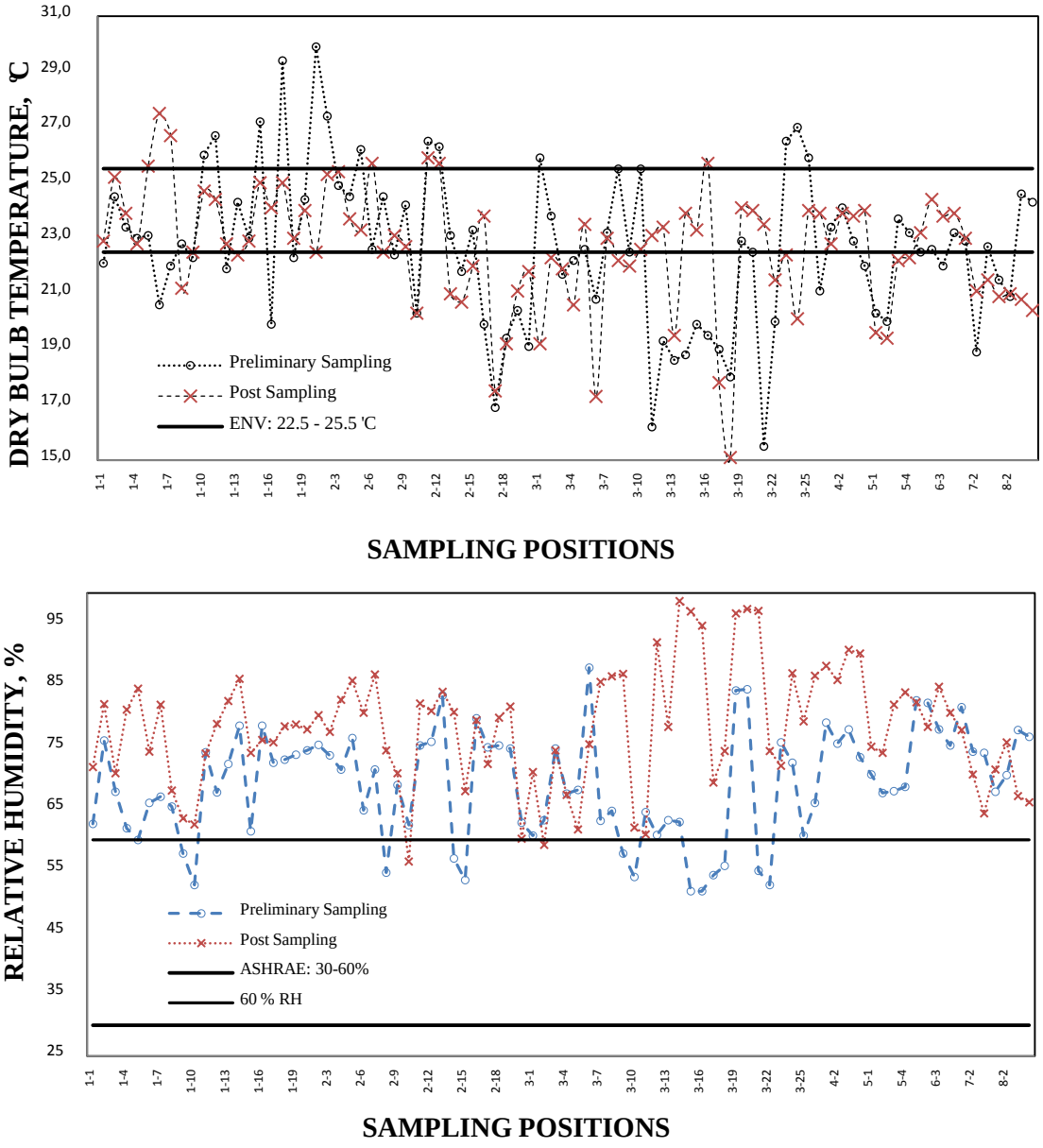


Figure 7.3: Air temperature and relative humidity measurements in building

7.3.1.2 Evaluation of Particulate Matter

The recommended threshold limit for suspended particulate matter in the guideline (DOSH, 2005; ENV, 1996) is 150 μg/m^3. Figure 7.4 shows tthat he average concentration of indoor particulates 62 μg/m^3 before decontamination, whereas the value decreases to 47 μg/m^3 after decontamination. The average concentration for all locations before and after the decontamination process is nearly similar, with a value of 9 and 8 μg/m^3, respectively. This indicates that particulate matter is not the main factor contributing to the decrease in microbial count.

In this study, the average concentration of suspended particulate matter is similar before and after the decontamination. Hence, it is deduced that particulate matter does not influence the microbial decontamination results during this research.

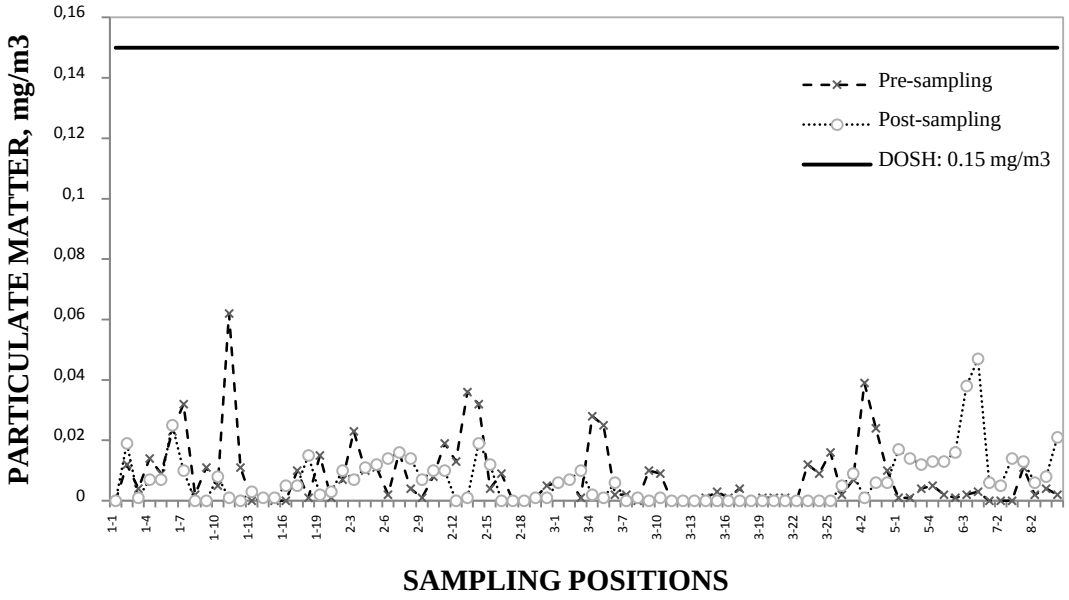


Figure 7.4: Suspended particulate matter measurements in building

7.3.1.3 Evaluation of Microbial Pollutants

The recommended threshold level for total bacteria count, and fungi and mould count is 500 CFU m^{-3} (ASHRAE, 2008) for general area. It is observed from Figure 7.5 that the values obtained are all well below the 500 CFU m^{-3} thresholds after vapour decontaminations. The average bacteria count is reduced by 84.6%, from 120.3 to 18.5 CFU m^{-3} (Table 7.1). The average fungi and mould count is reduced by 51.4%, from 70.8 to 34.4 CFU m^{-3} (Table 7.1).

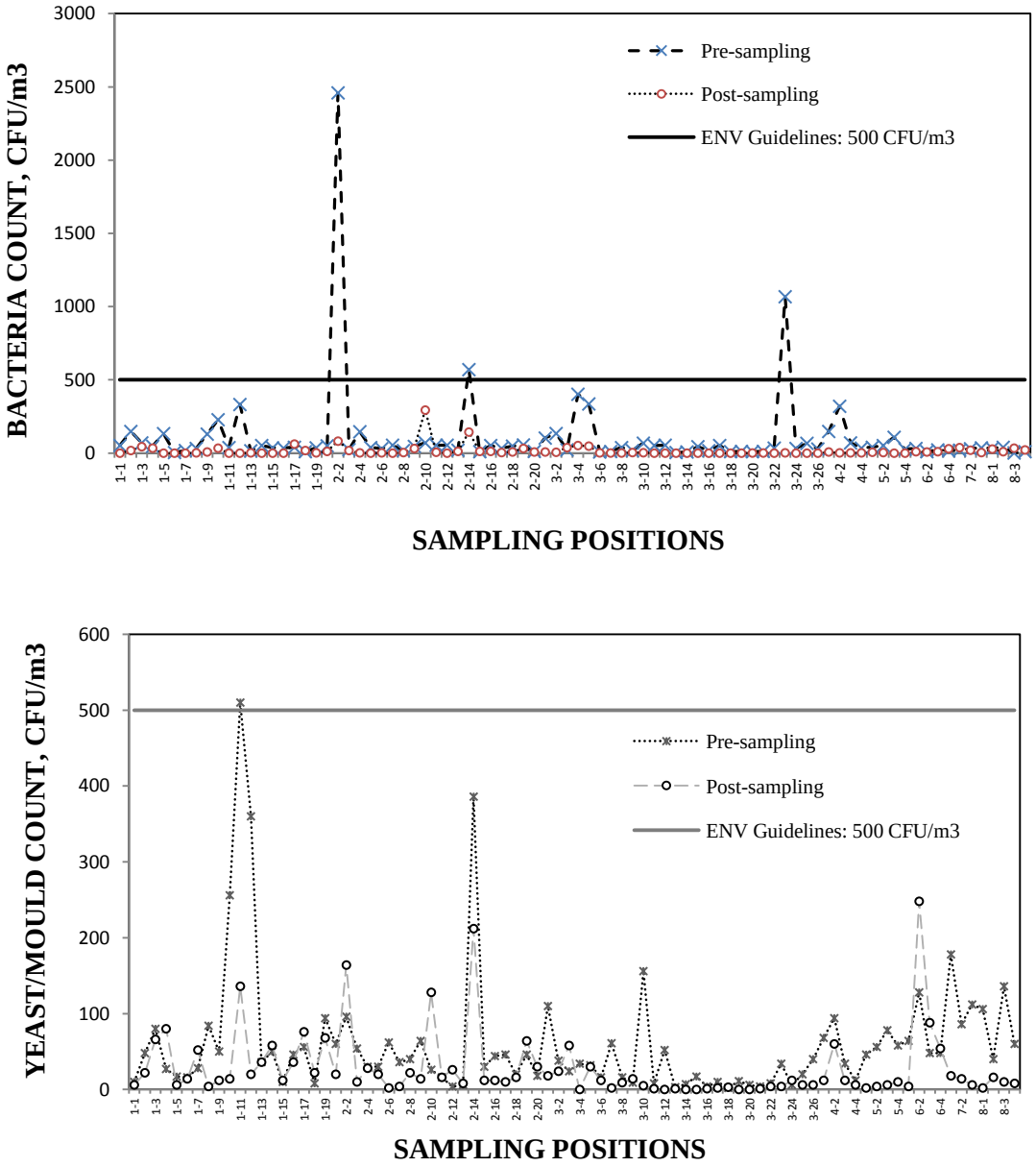


Figure 7.5: Bacteria count, fungi and mould count in the building.

7.3.2 Critical Area

7.3.2.1 Evaluation of Air Temperature and Relative Humidity

The air temperature and relative humidity measurements are presented in Figure 7.6. The air dry-bulb temperature recorded for 26 locations in critical areas ranges between 15.5 and 25.9 ℃ before decontamination, with an average air temperature 21.1 ℃. The ASHRAE standard recommends that the operating room temperature has a range of 20-23 ℃ (ASHRAE, 2008).

Measurements are repeated at the same locations after the decontamination process. The air dry-bulb temperature ranges between 15.1 and 25.7 ℃, with an average of air temperature of 21.8 ℃. From the measurements, there are only seven sampling location, which fulfil the requirement for both pre and post decontamination.

Most relative humidity measurements for both cases are above the recommended range of 30-60 % RH (ASHRAE, 2008), with a value of of 64.3% RH and 80.3% RH before and after decontamination, respectively. High humidity is probably caused by the same problems faced by the general area. Detailed data are shown in Appendix H.

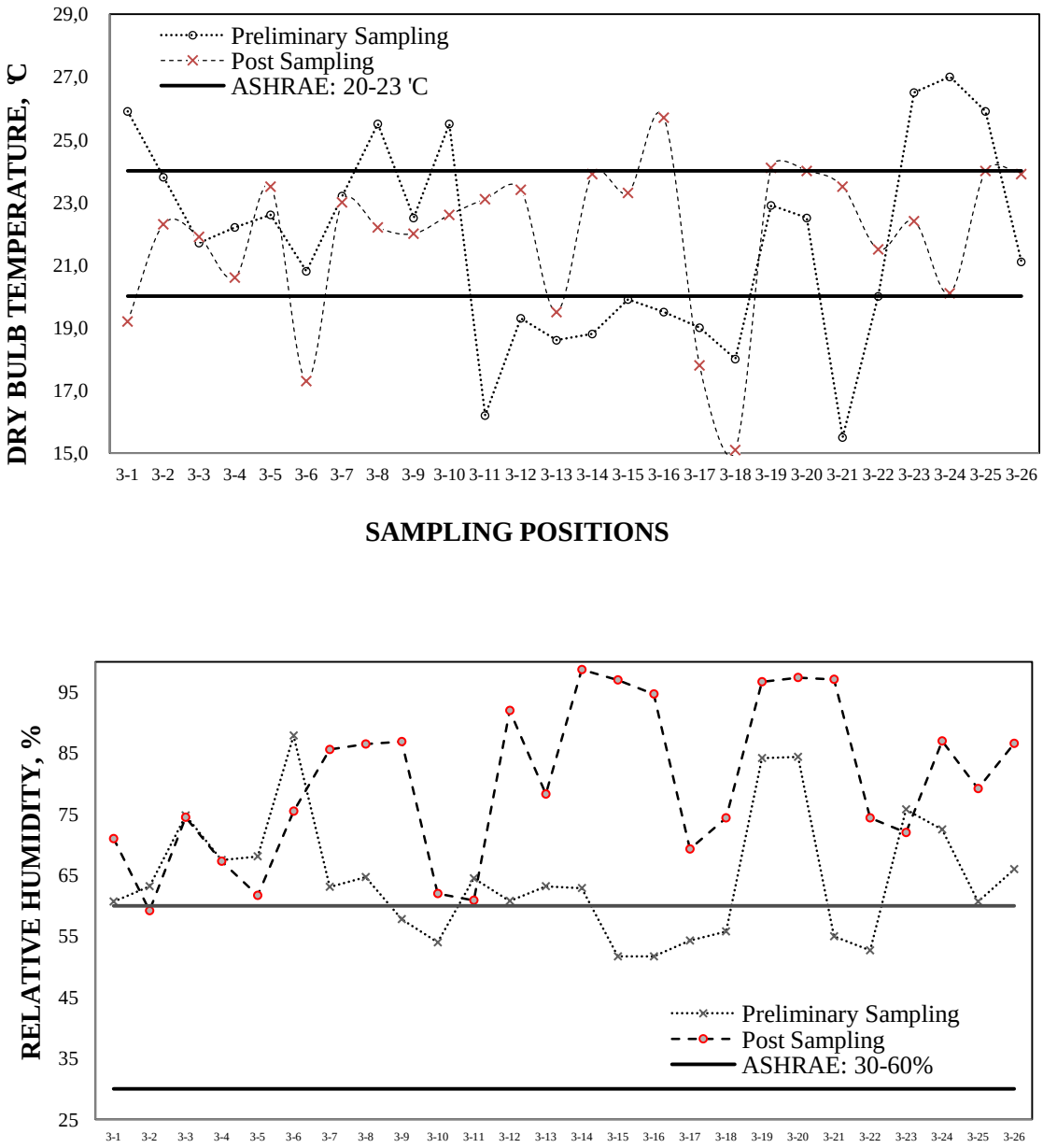


Figure 7.6: Air temperature and relative humidity measurements in critical area

7.3.2.2 Evaluation of Particulate Matter

Figure 7.7 shows the average concentration of indoor particulates with a concentration of 28 µg/m^3 before decontamination, and 10 µg/m^3 after decontamination. These values are less than suggested limit of 150 µg/m^3 (DOSH, 2005; ENV, 1996). The average concentration for all locations is similar before and after the decontamination, with a value of 4.9 µg/m^3 and 1.6 µg/m^3, respectively. This indicates that particulate matter is not the primary factor contributing to the reduction in microbial count.

The average concentration of suspended particulate matter for critical area is reduced during sampling after decontamination due to the cleaning process. The reduction in microbial count may be affected by the reduction in dust which it may act as a transport medium.

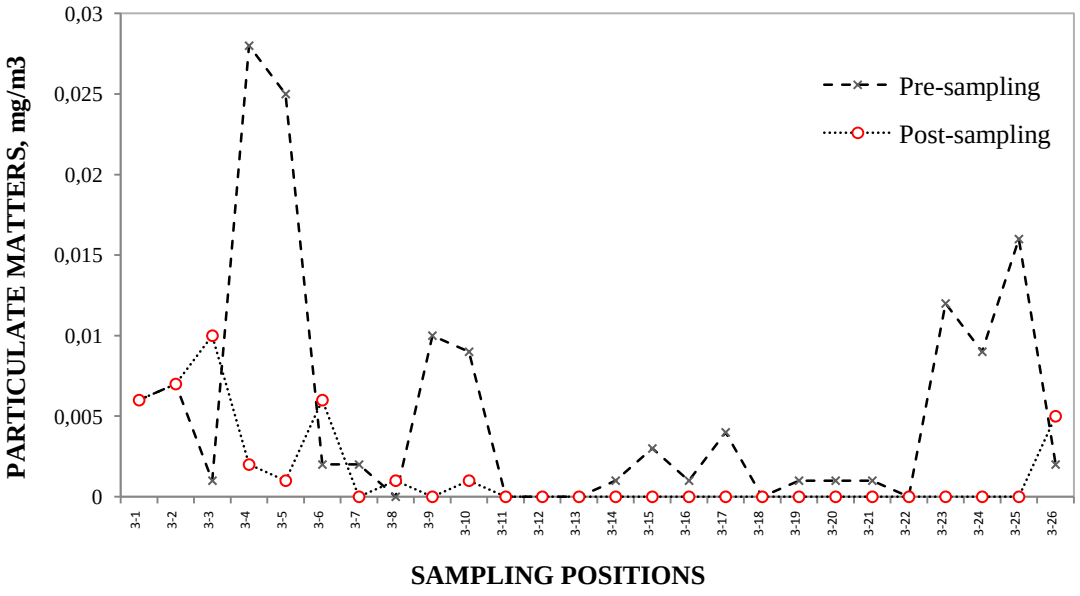


Figure 7.7: Suspended particulate matter measurements in critical area

7.3.2.3 Evaluation of Microbial Pollutants

For conventional operating rooms, the minimum standard for microbial air count is 35 CFU m^{-3} when the theatre is empty (HTM2025, 1994a; MOH, 2010). The average bacteria count is reduced by 88.3%, from 70.1 to 8.2 CFU m^{-3} (Table 7.1). The average yeast and mould count is reduced by 70.8% from 30.8 to 9 CFU m^{-3} (Table 7.1). Bacteria count is successfully reduced to the recommended level after decontamination using vapourized tea tree oil.

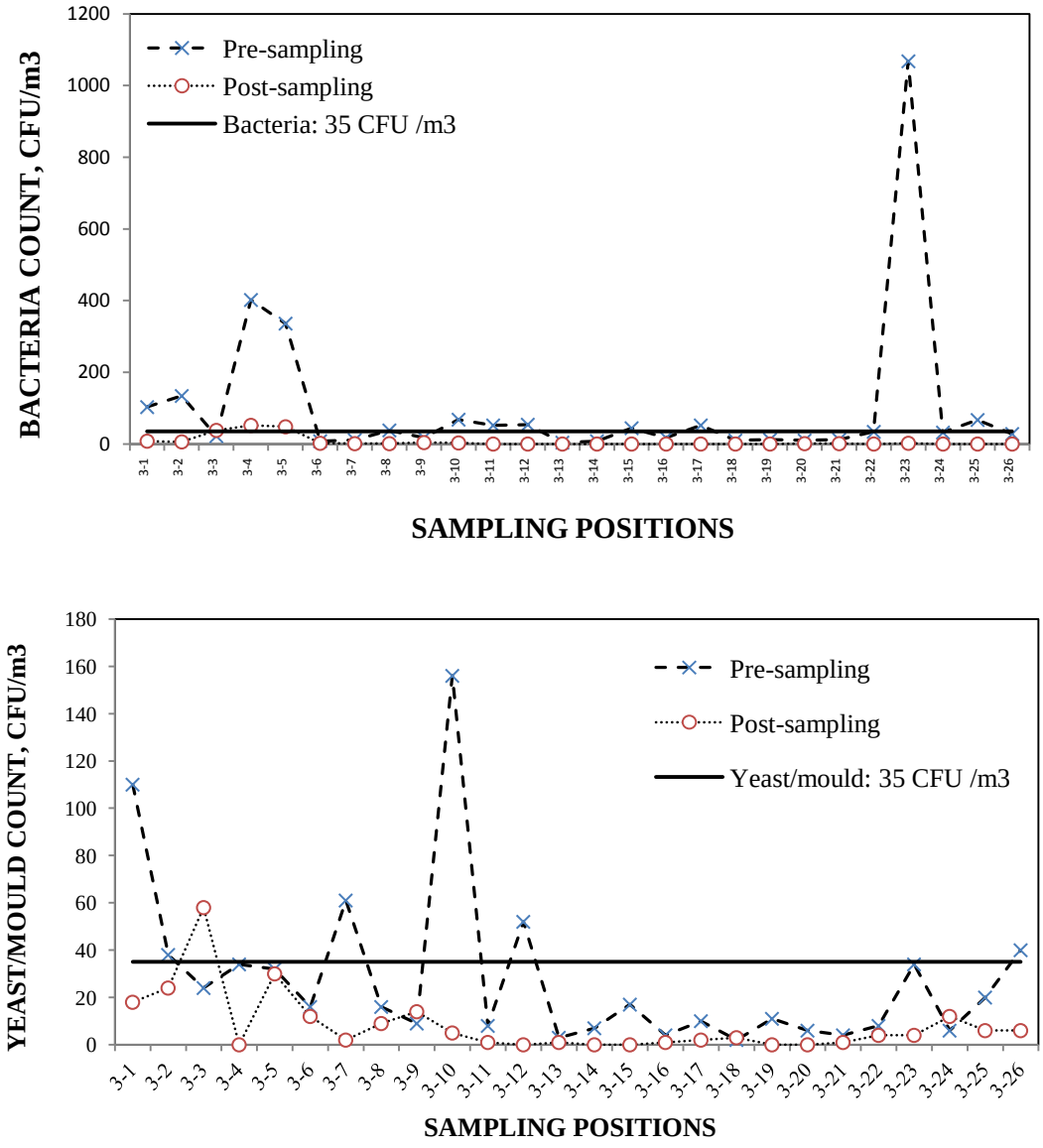


Figure 7.8: Bacteria count, fungi & mould count in critical area.

7.4 Summary

The overall results for microbial counts of bacteria, yeast and mould show that tea tree oil can be used as an alternative agent for vapour decontamination. This gaseous method is particular useful for decontaminating complex furniture and equipment, which is difficult to clean manually. Tea tree oil decontamination is easier and requires less equipment and procedure compared with vapour decontamination using hydrogen peroxide. Hence, the method is feasible for implementation.

Future investigation on the antibacterial properties of tea tree oil and other chemical disinfectants for indoor air is required. Due to the humid and hot environment of tropical climates which favour the growth of bacteria, yeast and mould, this investigation should account for the hot and humid environment associated with tropical climates.

Chapter 8. Chapter 8 will present the conclusions of the main findings in this research as well as recommendations for future work.

CHAPTER 8

CONCLUSION

8.0 Conclusions and Recommendations

This section draws the different strands of the dissertation into a comprehensive set of conclusions based on the main findings of this research, with a series of recommendations and scope for future work.

8.1 Conclusions

This dissertation focuses on case studies in different healthcare facilities with regards to three objectives. The first objective is to study the indoor air quality (IAQ) and thermal comfort conditions of a few healthcare facilities in Malaysia using physical and objective measurements. The data collected are analyzed by comparing to existing standards and guidelines. The second objective is to study the possibility of decontaminating microbial contaminants using vapourized tea tree oil. Finally, designated rooms are investigated to determine whether it fulfills its design purpose, the design features and operation of the ACMV system in room.

1. The results obtained from the field study in a pharmaceutical laboratory building indicate that the indoor chemical contaminant level is acceptable. Nevertheless, regular maintenance and careful examination needs to be conducted on the filters and ACMV system to ensure the air supplied to the room is cleaner. In the assessment on a newly commissioned hospital, the main contaminants exceed

the threshold limit for volatile organic compounds. However, they can be reduced by introducing fresh air for dilution. The centralized ACMV systems have better indoor air quality and temperature control compared with non-centralized ACMV systems. However, the occupants vote for better thermal comfort in non-centralized ACMV systems. This implies that occupants in Malaysian healthcare facilities prefer higher air temperature and relative humidity levels.

2. Decontamination of microbial contaminants, namely, bacteria, fungi and mould using vapourized tea tree oil has been evaluated. The air temperature, humidity and particulate concentration are measured and analyzed. The average air temperature, humidity and suspended particles matter values are similar before and after decontamination. Therefore, it is deduced that they are not the factors which influence the microbial decontamination results in this research. There is a significant reduction in the average values of bacteria, and fungi and mould count. The average bacteria, fungi and mould counts are reduced by 80% and 60%, respectively.
3. Simulation results on the air distribution in selected laboratory reveals that the air directed towards the workbench, which provides a clean working surface for product testing. However, due to improper maintenance, the air serves as a source of contaminants, polluting the tested products. The air velocities disperse when the high-speed region of the velocity profile moves towards the inner section of the room. Some contaminants are trapped at the corners of the room.

8.2 Recommendations

The work accomplished so far has created several new issues which require additional attention in future:

1. Since this study examines the IAQ conditions and thermal comfort for healthcare facilities in Malaysia, it is obvious that the amount of hospitals taken into study will reflect the actual findings of IAQ conditions and thermal comfort study. For this reason, it is imperative to cover a higher number of hospital by considering the age of the hospitals, ACMV systems, location (urban or rural area), building types (high-rise or ground buildings), etc.
2. The pharmaceutical laboratory building's characteristics are more closely related to clean space. The recent guideline in Malaysia for sterile pharmaceutical preparation facilities is more focused on the production of drugs. More investigation is needed to understand the IAQ and ACMV systems for this type of building.
3. It is important to determine the durability for decontamination of microbial pollutants. Further air samples need to be collected on a regular basis to understand the trend of microbial growth inside the building after decontamination. The research is carried at an unoccupied healthcare building. In order to gain more insight into the effect of decontamination by using vapourized tea tree oil, the research should be carried out at occupied hospitals, with regular monitoring. The study should also consider the potential use of other organic disinfectants which are safe and easy to handle.

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APPENDIX A

Indoor Air Contaminant Measurements in Pharmaceutical Laboratory Building

Table A-1: CO_2, CO concentration (ppm) in Chemistry unit

Chemistry unit									
Reading Results	Height	0.1m		0.6m		1.1m		1.6m	
	Point	CO	CO_2	CO	CO_2	CO	CO_2	CO	CO_2
	A1	1.64	707	1.7	709.5	1.46	833.5	1.6	853
	A2	1.57	702.5	1.4	765.5	1.46	828.5	1.6	804.5
	A3	1.26	704.5	1.1	783.5	1.6	827	1.8	793
	A4	1.07	851.5	0.9	865	1.73	870.5	1.8	915
	A5	0.8	854.5	1.2	862.5	1.83	878.5	1.9	948
	A6	1.04	860	1.6	869	1.88	874.5	2	957.5
Maximum Value		1.64	860	1.7	869	1.88	878.5	2	957.5
Minimum Value		0.8	702.5	0.9	709.5	1.46	828.5	1.6	793
Average Value		1.23	780	1.32	869	1.88	852	1.78	878.5

Table A-2: CO_2, CO concentration (ppm) in Chromatography Unit

Chromatography unit									
Reading Results	Height	0.1m		0.6m		1.1m		1.6m	
	Point	CO	CO_2	CO	CO_2	CO	CO_2	CO	CO_2
	B1	1.5	401.5	1.1	440	1.04	425.5	1	427
	B2	1.5	401.5	0.9	440	1.46	425.5	0.7	427
	B3	1.1	399	1.2	429.5	1.46	425	0.9	421.5
	B4	1.3	400	1.3	435	1.43	425	0.8	422
	B5	1	483	1.6	522.5	1.6	529	1.4	564
	B6	0.7	486	1.6	523	1.73	529	1.4	564
	B7	0.9	483	1.8	522.5	1.83	529	1	564
	B8	0.9	484	1.8	522.5	1.83	529	1	564
	B9	1.5	471	1.8	516.5	1.88	538.5	0.7	575
Maximum Value		1.5	486	1.8	522.5	1.88	538.5	1.4	575
Minimum Value		0.7	399	0.9	429.5	1.04	425	0.7	421.5
Average Value		1.15	445	1.46	483.5	1.58	484	0.99	503

Table A-3: CO_2 and CO average concentrations (ppm)

	Point	Chemistry Unit		Chromatography Unit	
		CO_2	CO	CO_2	CO
Reading Results	1	776	1.6	424	1.2
	2	775	1.5	424	1.1
	3	777	1.4	419	1.2
	4	876	1.4	421	1.2
	5	886	1.4	525	1.4
	6	890	1.6	526	1.4
	7	-	-	525	1.4
	8	-	-	525	1.4
	9	-	-	525	1.5
Maximum Value		890	1.6	526	1.5
Minimum Value		775	1.4	419	1.1
Overall (Average)		830	1.5	479	1.3

Table A-4: HCOH and TVOC average concentrations (ppm)

	Point	Chemistry Unit		Chromatography Unit	
		HCOH	TVOC	HCOH	TVOC
Reading Results	1	0.055	0.97	0.034	0.4
	2	0.033	1.13	0.02	0.27
	3	0.033	1.90	0.02	0.13
	4	0.057	1.43	0.021	0.17
	5	0.057	0.67	0.021	0.13
	6	0.051	0.8	0.025	0.13
	7	-	-	0.025	0.13
	8	-	-	0.022	0.3
	9	-	-	0.022	0.43
Maximum Value		0.57	1.90	0.034	0.43
Minimum Value		0.33	0.67	0.02	0.13
Overall (Average)		0.047	1.15	0.023	0.23

Table A-5: Particle count/m^3 with different particle size in two laboratories

	Height	Chemistry Unit				Chromatography Unit			
	Point	**$PM_{0.3}$**	**$PM_{0.5}$**	**PM_1**	**PM_5**	**$PM_{0.3}$**	**$PM_{0.5}$**	**PM_1**	**PM_5**
Reading Results	1	8.72E+07	5.6E+06	9.23E+04	8.84E+03	9.73E+07	6.50E+06	1.24E+05	1.19E+04
	2	9.95E+07	6.7E+06	1.19E+05	1.49E+04	9.87E+07	6.75E+06	1.11E+05	5.11E+03
	3	1.02E+08	7.2E+06	1.11E+05	1.40E+04	9.33E+07	6.06E+06	1.33E+05	6.37E+03
	4	1.00E+08	7.1E+06	1.32E+05	9.80E+03	1.04E+08	7.35E+06	1.28E+05	2.12E+03
	5	8.32E+07	5.1E+06	8.56E+04	8.94E+03	9.49E+07	6.40E+06	1.09E+05	1.28E+03
	6	7.86E+07	4.8E+06	8.10E+04	1.49E+04	1.00E+08	7.35E+06	1.04E+05	4.66E+03
	7	-	-	-	-	9.90E+07	7.00E+06	1.21E+05	5.14E+03
	8	-	-	-	-	1.00E+08	7.07E+06	1.32E+05	6.84E+03
	9	-	-	-	-	1.02E+08	7.51E+06	1.38E+05	3.42E+03
Maximum Value		1.02E+08	7.2E+06	1.32E+05	1.49E+04	1.04E+08	7.51E+06	1.38E+05	1.19E+04
Minimum Value		7.86E+07	4.8E+06	8.10E+04	8.84E+03	9.33E+07	6.06E+06	1.04E+05	1.28E+03
Average Value		9.19E+07	6.09E+06	1.03E+05	1.19E+04	9.88E+07	6.89E+06	1.22E+05	5.21E+03

APPENDIX B

Thermal Comfort Parameter Measurements in Pharmaceutical Laboratory Building

Table B-1: Measurements of thermal comfort parameters in Chemistry unit

Chemistry Unit									
Point	Temperature (℃)			Relative Humidity (%)			Velocity (m/s)		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
1	22.9	23.05	23.0	60.3	61.15	60.8	0.01	0.25	0.11
2	22.4	23.1	22.9	60.35	61.2	60.7	0.00	0.2	0.12
3	22.5	23.1	22.9	60.3	61	60.7	0.03	0.22	0.1
4	22.7	23.2	23.0	60.15	60.4	60.3	0.04	0.2	0.1
5	22.7	23.2	23.0	60.05	60.45	60.2	0.00	0.2	0.06
6	22.8	23.1	23.1	60.15	60.5	60.3	0.00	0.29	0.16
Overall	22.69	23.1	22.98	60.28	60.72	60.50	0.00	0.21	0.11
ASHARE Standard	22.5 ~ 26.0			30 ~ 60			<0.25		
Singapore NEA Std	22.5 ~ 25.5			<70%			<0.25		

Table B-2: Measurements of thermal comfort parameters in Chromatography unit

Chromatography Unit									
Point	Temperature (℃)			Relative Humidity (%)			Velocity (m/s)		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
1	21.8	22.1	21.9	64.3	65.65	64.8	0.05	0.24	0.13
2	21.9	23.7	22.4	64.3	67.1	65.1	0.04	0.24	0.13
3	21.8	22.0	21.9	64.45	65.75	64.9	0.01	0.13	0.07
4	21.0	22.0	21.7	64.4	66.25	65.0	0.02	0.16	0.1
5	22.7	23.2	22.9	61.1	62.25	61.5	0.06	0.23	0.11
6	21.8	23.0	22.4	61.1	63.25	61.7	0.03	0.25	0.11
7	22.7	23.2	22.9	61.1	62.25	61.5	0.02	0.19	0.07
8	22.7	23.2	22.9	61.1	62.25	61.5	0.01	0.15	0.1
9	22.6	23.3	22.9	60.8	62.3	61.7	0.02	0.28	0.21
Overall	22.1	22.8	22.4	57.7	62.5	63.1	0.03	0.21	0.11
ASHARE Standard	22.5 ~ 26.0			30 ~ 60			<0.25		
Singapore NEA Std	22.5 ~ 25.5			<70%			<0.25		

APPENDIX C

Survey Data from Staff in Pharmaceutical Laboratory Building

Table C-1: Survey data for staff background, activity levels and clothing in Chromatography unit

Chromatography unit			
Staff Gender	**Number**	**Staff's Clothing**	**Number**
Male	5	shirt/tube top	0
Female	4	shirt/short-sleeve	3
Staff Personal Problem	**Number**	shirt/light weight blouse, long sleeve	1
Asthmatic	1	shirt/normal long-sleeve shirt	0
Sinusitis	1	shirt/long sleeve, turtleneck blouse	0
Eczema	1	shirt/coat	5
Smoker	2	skirt, dress/ light skirt, above knee	0
Wear Contact Lens	0	skirt, dress/ light skirt, below knee	1
Staff Activity Level	**Number**	skirt, dress/ heavy skirt, knee length	0
Reclining	0	sweaters/ sleeveless vest	0
Seated quitely	0	sweaters/ thin sweater	0
Standing relaxed	4	sweaters/ long & thin sleeves	1
Light activity, standing	1	sweaters/ long & thick sleeves	0
Medium activity, standing	2	trousers/ shorts	0
High activity	0	trousers/ walking shorts	0
		trousers/ light-weight trousers	1
		trousers/ normal trousers	7
		trousers/ flannel trousers	0
		sundries/ socks	6
		sundries/ shoes	8
		sundries/ boots	0
		sundries/ gloves	5
		jacket/ vest	1
		jacket/ light	1
		jacket/ jacket	1

Table C-2: Survey data for staff background, activity levels and clothing in Chemistry unit

Chemistry Unit			
Staff Gender	**Number**	**Staff's Clothing**	**Number**
Male	7	shirt/tube top	0
Female	3	shirt/short-sleeve	3
Staff Personal Problem	**Number**	shirt/light weight blouse, long sleeve	0
Asthmatic	0	shirt/normal long-sleeve shirt	4
Sinusitis	1	shirt/long sleeve, turtleneck blouse	1
Eczema	1	shirt/coat	2
Smoker	2	skirt, dress/ light skirt, above knee	0
Wear Contact Lens	0	skirt, dress/ light skirt, below knee	1
Staff Activity Level	**Number**	skirt, dress/ heavy skirt, knee length	3
Reclining	0	sweaters/ sleeveless vest	0
Seated quitely	0	sweaters/ thin sweater	0
Standing relaxed	3	sweaters/ long & thin sleeves	5
Light activity, standing	0	sweaters/ long & thick sleeves	0
Medium activity, standing	0	trousers/ shorts	0
High activity	1	trousers/ walking shorts	0
		trousers/ light-weight trousers	0
		trousers/ normal trousers	10
		trousers/ flannel trousers	0
		sundries/ socks	4
		sundries/ shoes	6
		sundries/ boots	0
		sundries/ gloves	0
		jacket/ vest	0
		jacket/ light	0
		jacket/ jacket	1

Table C-3: Survey data for thermal comfort and Symptoms in Chromatography unit

Chromatography Unit						
Weather During Survey	**No**	**Thermal Comfort Level**	**No**	**Vote Index**	**Symptoms (Air Quality Effects)**	**No**
Clear	6	Hot	0	3	Dry eyes	3
Mixed (sun & clouds)	2	Warm	0	2	Dry or irritated throats	4
Overcast	1	Slightly Warm	0	1	Headaches	4
		Neutral	2	0	noise irritation	3
		Slightly Cool	2	-1	Sleepiness	5
		Cool	3	-2	difficulty concentrating	3
		Cold	2	-3	Dizziness	2
					skin dryness, rash or itch	4
					chest tightness or breathing difficulties	3

Table C-4: Survey data for thermal comfort and symptoms in Chemistry unit

Chemistry Unit						
Weather During Survey	**No**	**Thermal Comfort Level**	**No**	**Vote Index**	**Symptoms (Air Quality Effects)**	**No**
Clear	4	Hot	0	+3	Dry eyes	3
Mixed (sun & clouds)	2	Warm	0	+2	Dry or irritated throats	3
Overcast	2	Slightly Warm	0	+1	headaches	0
		Neutral	3	0	noise irritation	0
		Slightly Cool	0	-1	sleepiness	3
		Cool	0	-2	difficulty concentrating	1
		Cold	1	-3	dizziness	0
					skin dryness, rush or itch	6
					chest tightness or breathing difficulties	0

Table C-5: Survey data for air movement and air quality in Chromatography unit

Chromatography Unit				
Level	**Air movement**	**Air quality**		
	(Still to Draughty)	**(Fresh to Stuffy)**	**(Odourless to Smelly)**	**(Clean to Dusty)**
1	0	0	0	1
2	1	0	1	0
3	3	2	0	1
4	3	5	4	3
5	1	1	1	1
6	0	0	0	0
7	0	0	0	0

Table C-6: Survey data for air movement and air quality in Chemistry unit

Chemistry Unit				
Level	**Air movement**	**Air quality**		
	(Still to Draughty)	**(Fresh to Stuffy)**	**(Odourless to Smelly)**	**(Clean to Dusty)**
1	2	0	0	0
2	0	0	3	1
3	2	3	1	4
4	4	6	3	3
5	1	1	2	1
6	0	0	0	0
7	0	0	0	0

Table C-7: Survey data for Odour in Chromatography unit

Odour Detection		Odour Types (From "Yes")				
		Cigarettes	Carpet	Stationary	Food	Others
Yes	0	0	0	0	0	0
No	9	N/A	N/A	N/A	N/A	N/A

Table C-8: Survey data for Odour im Chemistry unit

Odour Detection		Odour Types (From "Yes")				
		Cigarettes	Carpet	Stationary	Food	Others
Yes	2	0	0	0	0	2
No	8	N/A	N/A	N/A	N/A	N/A

Table C-9: Survey data for lighting quality in Chromatography unit

Level	Lighting Quality for Chromatography Unit				
	(Dark to Bright)	(Steady to Flickering)	(No Glare to Glare)	(Very Uniform to Very Uneven)	(Satisfy to Unsatisfied)
1	0	2	0	1	2
2	1	1	0	0	0
3	0	1	2	1	0
4	5	2	2	3	4
5	2	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0

Table C-10: Survey data for lighting quality in Chemistry unit

Level	Lighting Quality for Chemistry Unit				
	(Dark to Bright)	(Steady to Flickering)	(No Glare to Glare)	(Very Uniform to Very Uneven)	(Satisfy to Unsatisfied)
1	0	2	1	1	1
2	0	2	2	0	2
3	3	1	1	2	2
4	5	3	5	4	2
5	1	3	0	0	1
6	1	0	0	0	0
7	0	0	0	0	0

Table C-11: Survey data for noise in Chromatography unit

Level	Acoustics for Chromatography Unit	
	No noise from ventilation systems to too much noise from ventilation systems	**No other noise to too much other noise**
1	2	1
2	1	0
3	1	1
4	3	4
5	0	0
6	1	0
7	0	0

Table C-12: Survey data for noise in Chemistry unit

Level	Acoustics for Chemistry Unit	
	No noise from ventilation systems to too much noise from ventilation systems	**No other noise to too much other noise**
1	2	1
2	4	0
3	1	4
4	4	3
5	0	0
6	0	0
7	0	0

APPENDIX D

Measuring Instruments

Type of Instruments	Measuring parameter/ Function		
	1. PPM Formaldemeter htv and htv-M		
	Measurement	Formaldehyde (ppm)	
	Dimension	150x 80 x 34 mm	
	Range	0 – 10 ppm	
	Precision	2%	
	Accuracy	94% of all readings meet the NIOSH criteria for acceptable formaldehyde.	
	2. TSI AeroTrak (Particle Counter)		
	Measurement	Particles / m^3	
	Dimension	25.4 x 11.4 x 7.6 cm	
	Size range	0.3 – 20 µm	
	Flow rate	0.1 CFM with ±5% accuracy	
	Counting Efficiency	50% @ 0.3µm; 100% for particles > 0.45µm	
	3. MiniRAE 2000 Portable VOC Monitor (model PGM 7600)		
	Measurement	Volatile organic compounds (ppm)	
	Dimension	21.8 x 7.62 x 5.08 cm	
	Range	0-10,000 ppm	
	Accuracy	±2 ppm or ±10% of reading < 2000 ppm ±20% of reading > 2000 ppm	
	Operating temp	-10 ℃ to 40 ℃	
	4. IAQ Monitor KANOMAX (model 2211)		
	CO	Range	0-500PPM
		Accuracy	±3% of reading or ±3PPM
	CO_2	Range	0-5000PPM
		Accuracy	±3% of reading or ±50PPM
	Temperature	Range	-20 to 60 ℃
		Accuracy	±0.5 ℃
	Relative humidity	Range	2-98%RH
		Accuracy	2-80%RH; ±2%RH, 80-98%RH; ±3%RH
	5. Extech 407117 Heavy Duty Mini Vane CFM Thermo Anmometer		
	Air velocity	Range	0.80 – 12.00 m/s
		Accuracy	±2% or 0.2 m/s
	Air Temperature	Range	0 - 80 ℃
		Accuracy	±0.8 ℃
	Dimension	178 x 74 x 33 mm	
	Operating RH	Max: 80%RH	
	Operating Temperature	Meter: 0 to 50 ℃; sensor: 0 to 80 ℃	

Type of Instruments	Measuring parameter/ Function		
	6. Alnor Thermal Anemometers Model AVM440-A		
	Velocity	Range	0 to 30 m/s
		Accuracy	±3% of reading or ±0.015m/s
	Temperature	Range	-18 to 93 ℃
		Accuracy	±0.3 ℃
	Humidity	Range	0 to 95% RH
		Accuracy	±3% RH
	7. ALNOR CompuFlow IAQ Meters Model CF930		
	CO	Range	0 to 500 PPM
		Accuracy	±3% of reading, or ±3PPM
	CO_2	Range	0 TO 5000PPM
		Accuracy	±3% of reading, or ±50PPM
	Temperature	Range	0 to 60 ℃
		Accuracy	±0.6 ℃
	Humidity	Range	5 to 95% RH
		Accuracy	±3.0% RH
	8. ALNOR Thermohygrometers Model TH720		
	Temperature	Range	0 to 60 ℃
		Accuracy	±0.6 ℃
	Humidity	Range	5 to 95% RH
		Accuracy	±3.0% RH
	9. TSI DuskTrak II Aerosol Monitor Model 8532		
	Measurement		Dust in mg/m^3
	Range		0.001 to 150 mg/m^3
	Accuracy		±0.1% of reading or 0.001 mg/m^3
	Particle Size Range		Approximately 0.1 to 10μm
	Flow rate		3.0L/min set at factory
	Flow Accuracy		±5% factory setpoint
	Dimension		4.9 x 4.75 x 12.45 inch
	Operational Temperature		0 to 50 ℃
	10. SAS Super 100		
	Specimen		Air
	Flow rate		100 L/min
	Flow Accuracy		±5% of aspirated air
	Dimension		105 x 110 x 290 mm
	Sampling efficiency		The effective sampling efficiency of the SAS SUPER 100, in a controlled environment, with aerosol of known particle size is 100% over 4 microns in size.

APPENDIX E

Questionnaire Form

SURVEY FORM

This survey is part of a study to evaluate the current thermal conditions of the selected hospital, especially the operating rooms. We appreciate your feedback in this evaluation.

Ref No:
Date:
Time:

1. Hospital Name:

2. Gender: Male □ Female □ 3. Age:

4. Occupant Location:

5. Sky: Clear □ Mixed(sun & clouds) □ Overcast □

6. Do you often experience the following symptoms?

□ Dry eyes
□ Dry or irritated throat
□ Headaches
□ Noise irritation
□ Sleepiness
□ Difficulty concentrating
□ Dizziness
□ Skin dryness, rash or itch
□ Chest tightness or breathing difficulty

7. Have you ever had asthmatic problems? □

8. Have you ever suffered from sinusitis? □

9. Have you ever suffered from eczema? □

10. Are you currently a smoker? □

11. Do you wear contact lens? □

12. Occupant Activity Level *(Tick the one that is most suitable)*

Reclining □ □ □ □ □ □ □ High activity

13. How would you describe your typical thermal comfort?

Hot □ □ □ □ □ □ □ Cool

14. How would you describe the cleanliness?

Unsatisfactory □ □ □ □ □ □ □ Satisfactory

15. Do you detect any odor?

□ Yes □ No

If yes, please indicate against the relevant sources. (You may tick more than one box)

□ Cigarettes □ Carpet □ Stationary □ Food □ Others

Cont'

Cont”

16. How would you describe the indoor condition in this area?

Please tick only one box per scale. The boxes within edges represent the ideal point on each scale

a) Air movement	Still	□ □ □ □ □ □ □	Draughty
b) Air quality	Fresh	□ □ □ □ □ □ □	Stuffy
	Odorless	□ □ □ □ □ □ □	Smelly
	Clean	□ □ □ □ □ □ □	Dusty
c) Lighting	Too dark	□ □ □ □ □ □ □	Too bright
	Steady	□ □ □ □ □ □ □	Flickering
	No glare	□ □ □ □ □ □ □	Too much glare
	Very uniform	□ □ □ □ □ □ □	Very uneven
	Satisfactory overall	□ □ □ □ □ □ □	Unsatisfactory overall
d) Acoustics	No noise from ventilation system	□ □ □ □ □ □ □	Too much noise from ventilation system
	No other noise	□ □ □ □ □ □ □	Too much other noise

17. Occupant’s clothing

Shirt:
- □ Tube top
- □ Short-sleeve
- □ Light weight blouse, long sleeves
- □ Light weight, long sleeves
- □ Normal long-sleeve shirt
- □ Long sleeves, turtleneck blouse
- □ Coat

Skirts, dresses:
- □ Light skirt, above knee
- □ Light skirt, below knee
- □ Heavy skirt, knee length

Sweaters:
- □ Sleeveless vest
- □ Thin sweater
- □ Long & thin sleeves
- □ Long & thick sleeves

Trousers:
- □ Shorts
- □ Walking shorts
- □ Light-weight trousers
- □ Normal trousers
- □ Flannel trousers

Sundries:
- □ Socks
- □ Shoes
- □ Boots
- □ Gloves

Jacket:
- □ Vest
- □ Light summer jacket
- □ Jacket

APPENDIX F

Clothing Insulation and Activity Levels

TABLE B2
Garment Insulation[a]

Garment Description[b]	I_{clu} (clo)	Garment Description[b]	I_{clu} (clo)
Underwear		**Dress and Skirts[c]**	
Bra	0.01	Skirt (thin)	0.14
Panties	0.03	Skirt (thick)	0.23
Men's briefs	0.04	Sleeveless, scoop neck (thin)	0.23
T-shirt	0.08	Sleeveless, scoop neck (thick), i.e., jumper	0.27
Half-slip	0.14	Short-sleeve shirtdress (thin)	0.29
Long underwear bottoms	0.15	Long-sleeve shirtdress (thin)	0.33
Full slip	0.16	Long-sleeve shirtdress (thick)	0.47
Long underwear top	0.20	**Sweaters**	
Footwear		Sleeveless vest (thin)	0.13
Ankle-length athletic socks	0.02	Sleeveless vest (thick)	0.22
Pantyhose/stockings	0.02	Long-sleeve (thin)	0.25
Sandals/thongs	0.02	Long-sleeve (thick)	0.36
Shoes	0.02	**Suit Jackets and Vests[d]**	
Slippers (quilted, pile lined)	0.03	Sleeveless vest (thin)	0.10
Calf-length socks	0.03	Sleeveless vest (thick)	0.17
Knee socks (thick)	0.06	Single-breasted (thin)	0.36
Boots	0.10	Single-breasted (thick)	0.42
Shirts and Blouses		Double-breasted (thin)	0.44
Sleeveless/scoop-neck blouse	0.13	Double-breasted (thick)	0.48
Short-sleeve knit sport shirt	0.17	**Sleepwear and Robes**	
Short-sleeve dress shirt	0.19	Sleeveless short gown (thin)	0.18
Long-sleeve dress shirt	0.25	Sleeveless long gown (thin)	0.20
Long-sleeve flannel shirt	0.34	Short-sleeve hospital gown	0.31
Long-sleeve sweatshirt	0.34	Short-sleeve short robe (thin)	0.34
Trousers and Coveralls		Short-sleeve pajamas (thin)	0.42
Short shorts	0.06	Long-sleeve long gown (thick)	0.46
Walking shorts	0.08	Long-sleeve short wrap robe (thick)	0.48
Straight trousers (thin)	0.15	Long-sleeve pajamas (thick)	0.57
Straight trousers (thick)	0.24	Long-sleeve long wrap robe (thick)	0.69
Sweatpants	0.28		
Overalls	0.30		
Coveralls	0.49		

a Data are from Chapter 8 in the *2001 ASHRAE Handbook—Fundamentals*.
b "Thin" refers to garments made of lightweight, thin fabrics often worn in the summer; "thick" refers to garments made of heavyweight, thick fabrics often worn in the winter.
c Knee-length dresses and skirts.
d Lined vests.

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Figure F-1: Clothing insulation

(This is a normative appendix and is part of this standard.)

NORMATIVE APPENDIX A—ACTIVITY LEVELS

Metabolic Rates for Typical Tasks

Activity	Met Units	Metabolic Rate W/m^2	Metabolic Rate $(Btu/h \cdot ft^2)$
Resting			
Sleeping	0.7	40	(13)
Reclining	0.8	45	(15)
Seated, quiet	1.0	60	(18)
Standing, relaxed	1.2	70	(22)
Walking (on level surface)			
0.9 m/s, 3.2 km/h, 2.0 mph	2.0	115	(37)
1.2 m/s, 4.3 km/h, 2.7 mph	2.6	150	(48)
1.8 m/s, 6.8 km/h, 4.2 mph	3.8	220	(70)
Office Activities			
Seated, reading, or writing	1.0	60	(18)
Typing	1.1	65	(20)
Filing, seated	1.2	70	(22)
Filing, standing	1.4	80	(26)
Walking about	1.7	100	(31)
Lifting/packing	2.1	120	(39)
Driving/Flying			
Automobile	1.0-2.0	60-115	(18-37)
Aircraft, routine	1.2	70	(22)
Aircraft, instrument landing	1.8	105	(33)
Aircraft, combat	2.4	140	(44)
Heavy vehicle	3.2	185	(59)
Miscellaneous Occupational Activities			
Cooking	1.6-2.0	95-115	(29-37)
House cleaning	2.0-3.4	115-200	(37-63)
Seated, heavy limb movement	2.2	130	(41)
Machine work			
sawing (table saw)	1.8	105	(33)
light (electrical industry)	2.0-2.4	115-140	(37-44)
heavy	4.0	235	(74)
Handling 50 kg (100 lb) bags	4.0	235	(74)
Pick and shovel work	4.0-4.8	235-280	(74-88)
Miscellaneous Leisure Activities			
Dancing, social	2.4-4.4	140-255	(44-81)
Calisthenics/exercise	3.0-4.0	175-235	(55-74)
Tennis, single	3.6-4.0	210-270	(66-74)
Basketball	5.0-7.6	290-440	(92-140)
Wrestling, competitive	7.0-8.7	410-505	(129-160)

Figure F-2: Metabolic rate for typical task

APPENDIX G

Biological Contaminants Measurements in SIMC

Table G-1: Bacteria and fungi & mould measurements in Level 1

Level	Department	Room	Sampling Point	Bacteria		Fungi	
				Bacteria Pre-Sampling	Bacteria Post-Sampling	Fungi and mould Pre-Sampling	Fungi and mould Post-Sampling
1	Material Management	Corridor	1-1	52	0	10	6
	Staff Facilities	Staff Change/Lockers	1-2	148	18	48	22
	Mortuary	Corridor in front of Muslim Body Storage	1-3	70	44	80	66
	Pharmacy	Ward Supply Dispensary Area	1-4	47	34	27	80
	Laboratory/ Pathology	Corridor Junction	1-5	133	0	17	6
		Main Biochemistry Lab	1-6	4	0	16	14
		Main Bacteriology Lab	1-7	18	0	28	52
	Administration	General Office (Finance)	1-8	32	2	84	4
		General Office (Admin & Operation)	1-9	130	8	50	12
	Medical Records	Medical Records	1-10	228	34	256	14
	I.T.	Staff Rest Room	1-11	38	0	510	136
		CPU Server Room	1-12	332	0	360	20
	Cancer Centre	Nurse Base	1-13	16	2	36	36
		Corridor in front of Doctor Office 2	1-14	52	0	50	58
		Linear Accell. Room 1	1-15	36	0	10	12
		Linear Accell. Room 2	1-16	34	TNTC	46	36
		Treatment Room	1-17	40	62	56	76
		Cyto Lab	1-18	10	18	8	22
		Isolation Room	1-19	36	2	94	68

Table G-2: Bacteria and fungi & mould measurements in Level 2

Level	Department	Room	Sampling Point	Bacteria		Fungi	
				Bacteria Pre-Sampling	Bacteria Post-Sampling	Fungi and mould Pre-Sampling	Fungi and mould Post-Sampling
2	Nursing Admin.	General Office	2-1	50	12	60	20
		Main Waiting	2-2	2460	82	96	164
	Wellness & Heart Centre	Treatment Room	2-3	24	18	54	10
		Between two Pat. Prep/Recovery	2-4	146	2	30	28
		Reception (Wellness)	2-5	38	0	30	20
	Kidney & Stone Centre	Nurse Base	2-6	30	2	62	2
		Treatment Room	2-7	54	0	36	4
	Physiotherapy	Between Gymnasium & Corridor	2-8	18	4	40	22
		Public Amenities (MPA) 1	2-9	46	32	64	14
		Public Amenities (MPA) 2	2-10	70	294	26	128
	SOC 1, 2 & 3	Treatment Room 1	2-11	54	6	16	16
		Treatment Room 2	2-12	54	0	4	26
	Accident & Emergency	Treatment Cubicles 2	2-13	20	12	6	8
	Doctor’s office	Corridor in front of Doctor's Office 3	2-14	570	144	386	212
		Corridor	2-15	10	12	30	12
	Imaging	Sub Wait Group 1	2-16	52	12	44	12
		General Radiography	2-17	32	4	46	10
		Equipment Store	2-18	48	8	20	16
		Work Area Group	2-19	56	32	46	64
	General Admin.	Admission Counter	2-20	12	8	18	30

Table G-3: Bacteria and fungi & mould measurements in Level 3

Level	Department	Room	Sampling Point	Bacteria		Fungi	
				Bacteria Pre-Sampling	Bacteria Post-Sampling	Fungi and mould Pre-Sampling	Fungi and mould Post-Sampling
3	CCU	Cubicle 5	3-1	103	8	110	18
		Isolation Room 1	3-2	134	6	38	24
		Fluoroscopy	3-3	22	38	24	58
	ICU	Isolation Room 1	3-4	402	52	34	0
		Isolation Room 2	3-5	336	48	32	30
		in front of Bay 5	3-6	8	2	16	12
	Operating Theatre	Pre-Op Holding 2	3-7	11	1	61	2
		Post-Anaesthesia Recovery 3	3-8	38	1	16	9
		in front of Anaesthesia Work Room	3-9	17	4	9	14
		To OT's Corridor	3-10	68	3	156	5
		Operating Room 1 (General)	3-11	52	0	8	1
			3-12	54	0	52	0
		Operating Room 2 (General)	3-13	4	0	3	1
			3-14	8	0	7	0
		Operating Room 3 (Neurology)	3-15	44	0	17	0
			3-16	17	0	4	1
		Operating Room 4 (General)	3-17	52	0	10	2
			3-18	10	0	2	3
		Operating Room 5 (Cardiac)	3-19	12	0	11	0
			3-20	10	1	6	0
		Operating Room 6 (Orthopaedic).	3-21	12	1	4	1

Level	Department	Room	Sampling Point	Bacteria		Fungi	
				Bacteria Pre-Sampling	Bacteria Post-Sampling	Fungi and mould Pre-Sampling	Fungi and mould Post-Sampling
3	Invasive Cardiac Laboratory	Invasive Cardiac Laboratory Room	3-22	34	0	8	4
	Cardiac Catheterization	Corridor	3-23	1068	2	34	4
	Central Sterile Supply	Sterilization Items Issue	3-24	32	0	6	12
		Main Packing Area	3-25	67	0	20	6
	Executive Administration	Board Room	3-26	28	0	40	6

Table G-4: Bacteria and fungi & mould measurements in Levels 4 to 8

Level	Department	Room	Sampling Point	Bacteria		Fungi	
				Bacteria Pre-Sampling	Bacteria Post-Sampling	Fungi and mould Pre-Sampling	Fungi and mould Post-Sampling
4	General Care & Day Surgery Unit	Treatment Room	4-1	148	8	68	12
		Day Lounge	4-2	320	2	94	60
	Pediatric Ward	Corridor	4-3	70	2	34	12
		Corridor	4-4	34	2	12	6
5	General Care Ward	Treatment Room	5-1	40	6	46	2
		Day Lounge	5-2	52	4	56	4
		Corridor	5-3	108	0	78	6
		Corridor	5-4	26	0	58	10
6	General Care Ward	Treatment Room	6-1	32	10	64	4
		Day Lounge	6-2	10	8	128	248
		Corridor	6-3	22	10	48	88
		Corridor	6-4	16	30	48	54
7	General Care Ward	Day Lounge	7-1	20	38	178	18
		Corridor	7-2	30	20	86	14
		Corridor	7-3	36	4	112	6
8	VIP Ward	Treatment Room	8-1	32	28	106	2
		Day Lounge	8-2	40	10	40	16
		Corridor	8-3	1	34	136	10
		Corridor	8-4	10	22	60	8

APPENDIX H

Indoor Air Contaminants and Physical Measurements in SIMC

Table H-1: Pre-sampling of indoor air contaminants and physical measurements in Level 1

Level	Department	Room	Sampling Point	Pre-Sampling					
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
1	Material Management	Corridor	1-1	0,1	508	1,1	0	22,1	62,6
	Staff Facilities	Staff Change/Lockers	1-2	0,0	334	2,8	0,012	24,5	76,1
	Mortuary	Corridor in front of Muslim Body Storage	1-3	0,0	452	0,1	0,004	23,4	67,8
	Pharmacy	Ward Supply Dispensary Area	1-4	0,3	382	0,3	0,014	23	61,9
	Laboratory/ Pathology	Corridor Junction	1-5	0,3	400	0,6	0,009	23,1	60
		Main Biochemistry Lab	1-6	0,0	350	0,3	0,023	20,6	66
		Main Bacteriology Lab	1-7	0,1	593	0,1	0,032	22	67
	Administration	General Office (Finance)	1-8	0,0	234	0,2	0,002	22,8	65,4
		General Office (Admin & Operation)	1-9	0,0	356	0,8	0,011	22,3	57,8
	Medical Records	Medical Records	1-10	0,0	318	0,1	0,005	26	52,7
	I.T.	Staff Rest Room	1-11	0,0	418	0,2	0,062	26,7	74,2
		CPU Server Room	1-12	0,5	488	0,9	0,011	21,9	67,7
	Cancer Centre	Nurse Base	1-13	0,0	462	0,0	0	24,3	72,3
		Corridor in front of Doctor Office 2	1-14	0,0	462	0,0	0,001	23	78,5
		Linear Accell. Room 1	1-15	0,0	247	0,0	0	27,2	61,4
		Linear Accell. Room 2	1-16	0,0	333	0,4	0	19,9	78,5
		Treatment Room	1-17	0,0	408	0,0	0,01	29,4	72,5
		Cyto Lab	1-18	0,0	308	0,0	0,001	22,3	73
		Isolation Room	1-19	0,0	355	0,0	0,015	24,4	73,8

Table H-2: Pre-sampling of indoor air contaminants and physical measurements in level 2

Level	Department	Room	Sampling Point	Pre-Sampling					
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
2	Nursing Admin.	General Office	2-1	0,0	366	0,0	0,001	29,9	74,5
		Main Waiting	2-2	0,0	345	0,1	0,007	27,4	75,4
	Wellness & Heart Centre	Treatment Room	2-3	0,0	393	0,0	0,023	24,9	73,7
		Preparation/ Recovery	2-4	0,2	385	0,0	0,01	24,5	71,4
		Reception (Wellness)	2-5	0,3	374	0,6	0,011	26,2	76,5
	Kidney & Stone Centre	Nurse Base	2-6	0,1	392	0,0	0,002	22,6	64,8
		Treatment Room	2-7	0,2	385	0,4	0,016	24,5	71,4
	Physiotherapy	Between Gymnasium & Corridor	2-8	0,0	317	0,0	0,004	22,4	54,7
		Public Amenities (MPA) 1	2-9	0,0	382	0,0	0,001	24,2	68,9
		Public Amenities (MPA) 2	2-10	0,0	351	0,0	0,008	20,3	62,4
	SOC 1, 2 & 3	Treatment Room 1	2-11	0,1	322	7,5	0,019	26,5	75,3
		Treatment Room 2	2-12	0,0	393	3,4	0,013	26,3	75,9
	Accident & Emergency	Treatment Cubicles 2	2-13	0,0	361	2,3	0,036	23,1	83,4
	Doctor’s office	Corridor in front of Doctor's Office 3	2-14	0,0	352	0,0	0,032	21,8	57
		Corridor	2-15	0,1	387	0,0	0,004	23,3	53,5
	Imaging	Sub Wait Group 1	2-16	0,0	393	0,2	0,009	19,9	79,7
		General Radiography	2-17	0,0	379	0,2	0	16,9	75
		Equipment Store	2-18	0,0	368	0,2	0	19,4	75,3
		Work Area Group	2-19	0,3	300	0,4	0,001	20,4	74,8
	General Admin.	Admission Counter	2-20	0,0	483	0,0	0,005	19,1	62,8

Table H-3: Pre-sampling of indoor air contaminants and physical measurements in level 3

Level	Department	Room	Sampling Point	Pre-Sampling					
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
3	CCU	Cubicle 5	3-1	0,9	401	1,1	0,006	23,2	60,7
		Isolation Room 1	3-2	0,0	473	3,2	0,007	25,5	63,2
		Fluoroscopy	3-3	0,0	462	0,0	0,001	22,5	74,8
	ICU	Isol. Room 1	3-4	0,2	413	3,9	0,028	25,5	67,5
		Isol. Room 2	3-5	0,0	351	8,8	0,025	16,2	68,1
		in front of Bay 5	3-6	0,1	311	0,0	0,002	19,3	87,9
	Operating Theatre	Pre-Op Holding 2	3-7	0,0	315	0,0	0,002	18,6	63,1
		Post-Anaesthesia Recovery 3	3-8	0,2	302	0,8	0	18,8	64,7
		in front of Anaes. Work Room	3-9	0,0	314	0,0	0,01	19,9	57,8
		To OT's Corridor	3-10	0,0	351	0,3	0,009	19,5	54
		Operating Room 1 (General)	3-11	0,0	331	0,1	0	19	64,5
			3-12	0,0	326	0,0	0	18	60,8
		Operating Room 2 (General)	3-13	0,0	361	0,0	0	22,9	63,2
			3-14	0,0	394	0,0	0,001	22,5	62,9
		Operating Room 3 (Neurology)	3-15	0,0	312	0,0	0,003	15,5	51,7
			3-16	0,0	286	0,0	0,001	23,2	51,7
		Operating Room 4 (General)	3-17	0,0	388	0,1	0,004	25,5	54,3
			3-18	0,0	365	0,0	0	22,5	55,8
		Operating Room 5 (Cardiac)	3-19	0,0	309	0,8	0,001	25,5	84,2
			3-20	0,0	329	0,2	0,001	16,2	84,4
		Operating Room 6 (Orthopaedic)	3-21	0,2	375	0,1	0,001	19,3	55

Level	Department	Room	Sampling Point	Pre-Sampling					
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
3	Invasive Cardiac Laboratory	Invasive Cardiac Laboratory Room	3-22	0,3	487	0,0	0	20	52,7
	Cardiac Catheterization	Corridor	3-23	0,4	383	0,5	0,012	26,5	75,8
	Central Sterile Supply	Sterilization Items Issue	3-24	0,5	386	0,0	0,009	27	72,5
		Main Packing Area	3-25	0,9	401	0,0	0,016	25,9	60,7
	Executive Administration	Board Room	3-26	0,2	377	0,0	0,002	21,1	66

Table H-4: Pre-sampling of indoor air contaminants and physical measurements in levels 4 to 8

Level	Department	Room	Sampling Point	Pre-Sampling					
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
4	General Care & Day Surgery Unit	Treatment Room	4-1	0,5	331	0,3	0,007	23,4	79
		Day Lounge	4-2	0,0	371	0,0	0,039	24,1	75,6
	Pediatric Ward	Corridor	4-3	0,0	254	0,9	0,024	22,9	77,9
		Corridor	4-4	0,0	245	0,7	0,01	22	73,4
5	General Care Ward	Treatment Room	5-1	0,0	384	0,2	0,001	20,3	70,6
		Day Lounge	5-2	0,2	376	0,0	0,001	20	67,6
		Corridor	5-3	0,0	318	0,0	0,004	23,7	67,9
		Corridor	5-4	0,0	392	0,0	0,005	23,2	68,6
6	General Care Ward	Treatment Room	6-1	0,0	367	0,0	0,002	22,5	82,6
		Day Lounge	6-2	0,0	333	0,0	0,001	22,6	82,2
		Corridor	6-3	0,0	389	0,0	0,002	22	77,9
		Corridor	6-4	0,0	371	0,0	0,003	23,2	75,3
7	General Care Ward	Day Lounge	7-1	0,0	485	0,0	0	22,9	81,5
		Corridor	7-2	0,0	417	0,0	0	18,9	74,3
		Corridor	7-3	0,0	418	0,0	0	22,7	74,1
8	VIP Ward	Treatment Room	8-1	0,0	390	1,3	0,011	21,5	67,8
		Day Lounge	8-2	0,0	405	1,2	0,002	20,9	70,5
		Corridor	8-3	0,0	400	0,0	0,004	24,6	77,8
		Corridor	8-4	0,0	387	0,0	0,002	24,3	76,7

Table H-5: Post-sampling of indoor air contaminants and physical measurements in level 1

Level	Department	room	Sampling Point	Post-Sampling						
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	HCOH (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
1	Material Management	Corridor	1-1	0	378	0,4	0	0	22,9	71,8
	Staff Facilities	Staff Change/Lockers	1-2	0	453	0,2	0	0,019	25,2	82
	Mortuary	Corridor in front of Muslim Body Storage	1-3	0	412	8,5	0	0,001	23,9	70,8
	Pharmacy	Ward Supply Disp. Area	1-4	0	397	4,2	0,02	0,007	22,8	81,1
	Laboratory/ Pathology	Corridor Junction	1-5	0	327	0,8	0	0,007	25,6	84,5
		Main Biochemistry Lab	1-6	0	393	0,8	0	0,025	27,5	74,3
		Main Bacteriology Lab	1-7	0	470	0,1	0	0,01	26,7	81,9
	Administration	General Office (Finance)	1-8	0	314	0	0	0	21,2	68
		General Office (Admin & Operation)	1-9	0	394	0,3	0,01	0	22,5	63,5
	Medical Records	Medical Records	1-10	0	347	0	0	0,008	24,7	62,5
	I.T.	Staff Rest Room	1-11	0	456	0,9	0,01	0,001	24,4	74
		CPU Server Room	1-12	0	472	0	0	0	22,8	78,8
	Cancer Centre	Nurse Base	1-13	0	374	0,2	0	0,003	22,4	82,5
		Corridor in front of Doctor Office 2	1-14	0	385	0,5	0	0,001	22,9	86,1
		Linear Accell. Room 1	1-15	0	411	0,2	0	0,001	25	74,1
		Linear Accell. Room 2	1-16	0	353	0,9	0,03	0,005	24,1	76,2
		Treatment Room	1-17	0	322	2	0,1	0,005	25	75,8
		Cyto Lab	1-18	0	453	0,4	0	0,015	23	78,4
		Isolation Room	1-19	0,2	487	1,4	0	0,002	24	78,7

Table H-6: Post-sampling of indoor air contaminants and physical measurements in level 2

Level	Department	Room	Sampling Point	Post-Sampling						
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	HCOH (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
2	Nursing Admin.	General Office	2-1	0	360	0	0,01	0,003	22,5	77,9
		Main Waiting	2-2	0	382	0,8	0,05	0,01	25,3	80,2
	Wellness & Heart Centre	Treatment Room	2-3	0	350	0,1	0	0,007	25,4	77,5
		Preparation/Recovery	2-4	0	359	0	0	0,011	23,7	82,7
		Reception (Wellness)	2-5	0	412	0,6	0	0,012	23,3	85,8
	Kidney & Stone Centre	Nurse Base	2-6	0	397	0	0,01	0,014	25,7	80,6
		Treatment Room	2-7	0	377	0,7	0	0,016	22,5	86,8
	Physiotherapy	Between Gymnasium & Corridor	2-8	0,3	402	1,6	0,1	0,014	23,1	74,5
		Public Amenities (MPA) 1	2-9	0,1	389	0	0	0,007	22,7	70,8
		Public Amenities (MPA) 2	2-10	0	394	0	0	0,01	20,3	56,5
	SOC 1, 2 & 3	Treatment Room 1	2-11	0	412	2,1	0	0,01	25,9	82,1
		Treatment Room 2	2-12	0	462	0,7	0	0	25,7	80,9
	Accident & Emergency	Treatment Cubicles 2	2-13	0	384	5,7	0	0,001	21	84
	Doctor’s office	Corridor in front of Doctor's Office 3	2-14	0	369	0,1	0,09	0,019	20,7	80,7
		Corridor	2-15	0	379	1,5	0,03	0,012	22	67,9
	Imaging	Sub Wait Group 1	2-16	0,1	391	0,8	0,03	0	23,8	79,4
		General Radiography	2-17	0	418	0,1	0,02	0	17,5	72,3
		Equipment Store	2-18	0	310	0,4	0,08	0	19,2	79,8
		Work Area Group	2-19	0	459	0,7	0	0,001	21,1	81,6
	General Admin.	Admission Counter	2-20	0	427	0	0	0,001	21,8	60,2

Table H-7: Post-sampling of indoor air contaminants and physical measurements in level 3

Level	Department	Room	Sampling Point	Post-Sampling						
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	HCOH (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
3	CCU	Cubicle 5	3-1	0,0	422	0,2	0,00	0,006	19,2	71
		Isolation Room 1	3-2	0,0	490	0,5	0,09	0,007	22,3	59,2
		Fluoroscopy	3-3	0,2	389	9,3	0,05	0,01	21,9	74,5
	ICU	Isolation Room 1	3-4	0,0	361	1,2	0,00	0,002	20,6	67,3
		Isolation Room 2	3-5	0,0	350	2,8	0,08	0,001	23,5	61,7
		in front of Bay 5	3-6	0,0	304	0,1	0,00	0,006	17,3	75,5
	Operating Theatre	Pre-Op Holding 2	3-7	0,0	472	0,8	0,00	0	23	85,6
		Post-Anaesthesia Recovery 3	3-8	0,0	385	0,0	0,00	0,001	22,2	86,5
		in front of Anaesthesia Work Room	3-9	0,0	498	1,3	0,00	0	22	86,9
		To OT's Corridor	3-10	0,0	472	1,8	0,00	0,001	22,6	62
		Operating Room 1 (General)	3-11	0,0	418	0,0	0,00	0	23,1	60,9
			3-12	0,0	390	0,0	0,00	0	23,4	92
		Operating Room 2 (General)	3-13	0,0	413	0,1	0,00	0	19,5	78,3
			3-14	0,0	338	0,0	0,00	0	23,9	98,7
		Operating Room 3 (Neurology)	3-15	0,0	444	0,0	0,00	0	23,3	97
			3-16	0,0	471	0,0	0,00	0	25,7	94,7
		Operating Room 4 (General)	3-17	0,0	399	0,5	0,00	0	17,8	69,3
			3-18	0,0	422	0,2	0,00	0	15,1	74,4
		Operating Room 5 (Cardiac)	3-19	0,0	442	0,0	0,00	0	24,1	96,7
			3-20	0,0	414	0,0	0,00	0	24	97,4
		Operating Room 6 (Orthopaedic)	3-21	0,0	364	0,0	0,00	0	23,5	97,1

Level	Department	Room	Sampling Point	Post-Sampling						
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	HCOH (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
3	Invasive Cardiac Laboratory	Invasive Cardiac Laboratory Room	3-22	0	354	0,3	0	0	21,5	74,4
	Cardiac Catheterization	Corridor	3-23	0	478	0	0,02	0	22,4	72
	Central Sterile Supply	Sterilization Items Issue	3-24	0	383	0	0,01	0	20,1	87
		Main Packing Area	3-25	0	376	0,4	0	0	24	79,2
	Executive Administration	Board Room	3-26	0	427	0,5	0	0,005	23,9	86,6

Table H-8: Post-sampling of indoor air contaminants and physical measurements in levels 4 to 8

Level	Department	room	Sampling Point	Post-Sampling						
				CO (ppm)	CO_2 (ppm)	TVOC (ppm)	HCOH (ppm)	Dust (mg/m^3)	Temperature (℃)	Relative Humidity (%)
4	General Care & Day Surgery Unit	Treatment Room	4-1	0	464	5,9	0,12	0,009	22,8	88,2
		Day Lounge	4-2	0	443	1,1	0,14	0,001	23,9	85,9
	Pediatric Ward	Corridor	4-3	0,3	513	0,2	0	0,006	23,8	90,8
		Corridor	4-4	0	498	0	0	0,006	24	90,2
5	General Care Ward	Treatment Room	5-1	0	399	1,2	0	0,017	19,6	75,1
		Day Lounge	5-2	0,1	432	0,2	0,03	0,014	19,4	74,1
		Corridor	5-3	0	476	3,8	0	0,012	22,2	81,9
		Corridor	5-4	0	486	5,8	0	0,013	22,3	83,9
6	General Care Ward	Treatment Room	6-1	0	385	3,1	0,02	0,013	23,2	82,3
		Day Lounge	6-2	0	473	1,7	0	0,016	24,4	78,3
		Corridor	6-3	0	385	3,4	0	0,038	23,8	84,8
		Corridor	6-4	0	489	4	0	0,047	23,9	80,6
7	General Care Ward	Day Lounge	7-1	0	392	0,8	0	0,006	23	77,8
		Corridor	7-2	0	472	0,6	0,04	0,005	21,1	70,6
		Corridor	7-3	0	351	0,9	0	0,014	21,5	64,3
8	VIP Ward	Treatment Room	8-1	0	359	2,9	0	0,013	20,9	71,4
		Day Lounge	8-2	0	360	0	0,02	0,006	21	75,8
		Corridor	8-3	0	471	0,3	0	0,008	20,8	67,1
		Corridor	8-4	0	385	3,2	0	0,021	20,4	66,1

APPENDIX I

Outdoor Air Quality Assessment in SIMC

Table I-1: Measurements for outdoor air quality assessment

Location (Zone)	Temperature (°C)	RH (%)	CO2 (ppm)	CO (ppm)	TVOC (ppm)	Bacteria (CFU/m^3)	Fungi (CFU/m^3)	Dust (mg/m^3)
A1: Close to AHU intake for tower block (TOW-1)	31.4	63.7	428	0.0	0.4	20	120	0.025
A2: Close to AHU intake for tower block (TOW-2)	32.0	65.0	374	0.0	0.0	10	100	0.027
A3: At the roof of tower block (TOW-1)	30.1	68.0	337	0.0	0.0	10	580	0.027
A4: Location: At the roof of tower block (TOW-2)	29.9	68.0	381	0.0	0.0	20	560	1.030
B1: Location: On the roof above OT	30.3	69.5	384	0.0	3.2	20	1260	0.028
B2: Location: On the roof above OT.	30.3	69.5	468	0.0	0.0	10	830	0.028
C1: Location: Outdoor area beside level 2 administration office	24.6	90.6	354	0.1	0.0	280	1380	0.016
D1: Location: Outdoor area next to the corridor of Wellness care centre.	30.6	65.3	440	0.0	0.0	0	30	0.025
D2: Location: Location: Outdoor area next to the corridor of Wellness care centre.	32.0	60.0	317	0.0	0.0	0	400	0.032
E1: Location: Outdoor area in front of entrance of IT Department	24.2	91.3	396	0.0	0.0	480	1270	0.017
F1: Location: Outdoor area near of entrance of Financial Administration Department	25.5	91.4	329	0.1	0.0	650	510	0.02
G1: Location: Outdoor area near to entrance of Accident & Emergency Department	25.4	87.7	435	0.4	0.0	50	1040	0.023

APPENDIX J

Sampling Locations for Outdoor Air Quality Assessment in SIMC

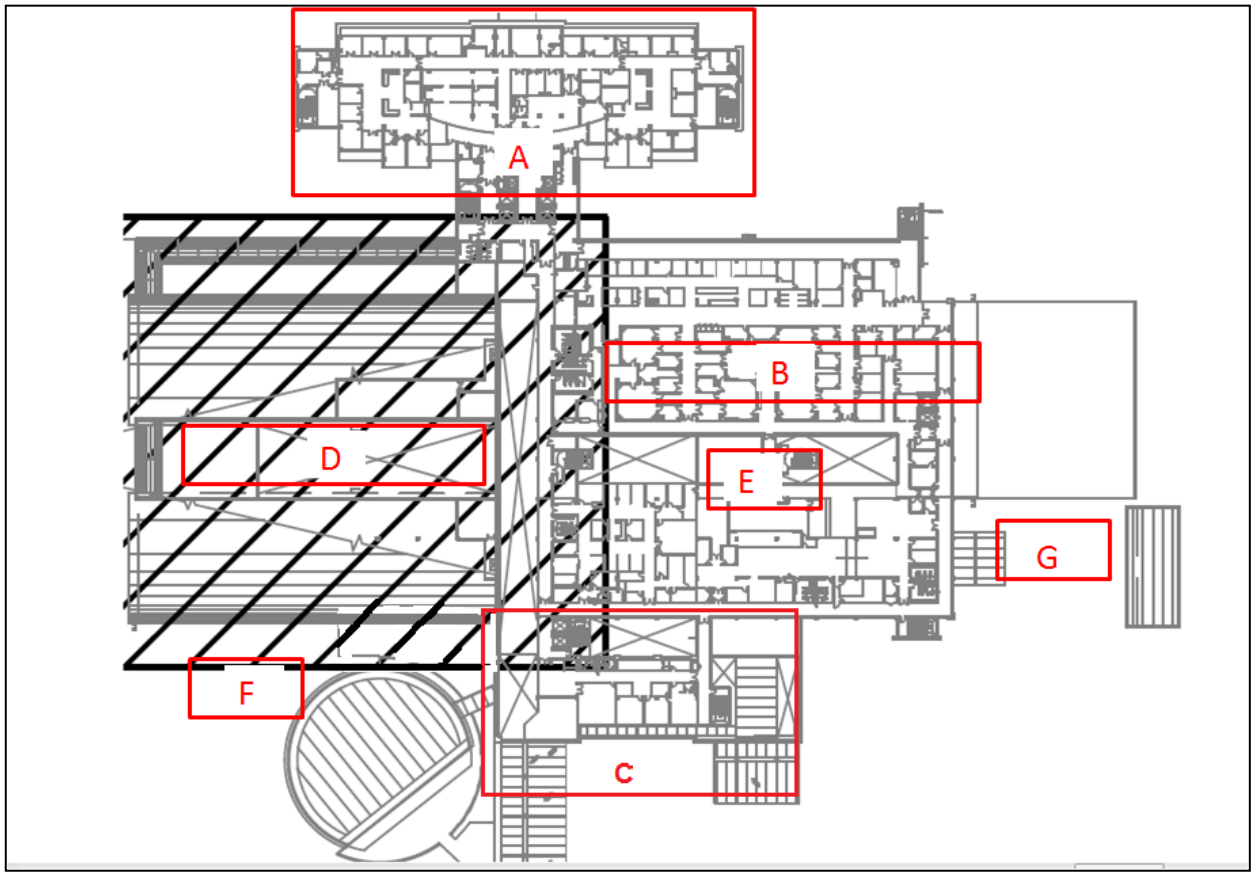

Figure J-1: Outdoor air sampling zones

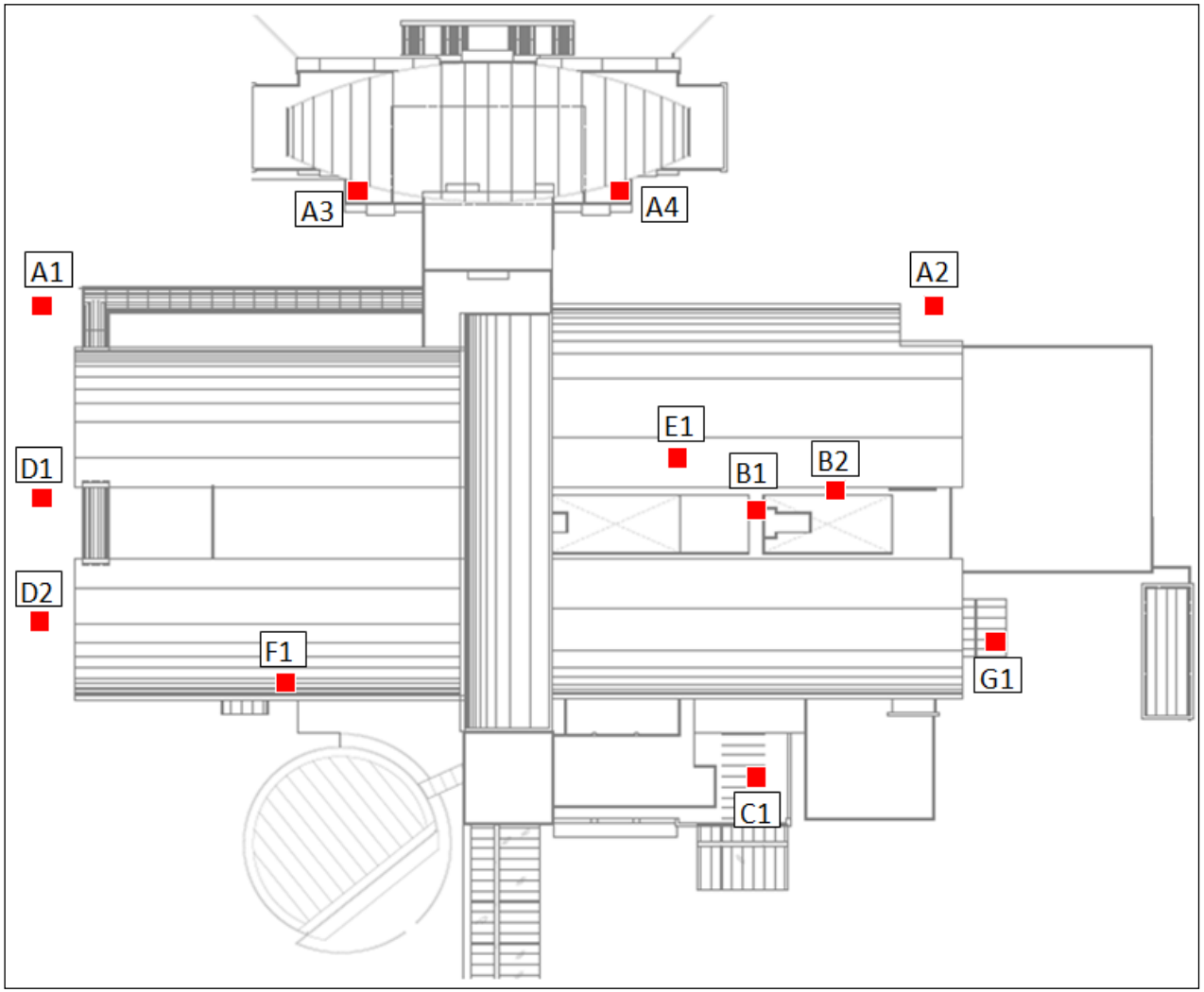

Figure J-2: Outdoor sampling locations

APPENDIX K

Indoor Air Contaminants and Physical Measurements in Four Hospitals

Table K-1: Indoor air contaminants and physical measurements in Banting Hospital

Hospital	Department	Sampling Point	Thermal Comfort Parameter				Indoor Air Contaminant			
			Air Temperature (℃)	Velocity (m/s)	RH (%)	MRT (℃)	CO (ppm)	CO_2 (ppm)	HCOH (ppm)	TVOC (ppm)
Banting (A)	Microbiology Lab	A1	24.8	0.58	6.36	27.7	0.23	690	0.00	0.60
	Donation Blood Room	A2	24.8	0.07	62.1	26.5	1.28	489	0.00	0.00
	Pathology Chemistry Room	A3	22.5	0.28	62.3	24.9	0.18	496	0.00	0.00
	Phathloghy Dispensary	A4	22.5	0.11	62.3	24.4	0.18	496	0.00	0.00
	Phathology Waiting Area	A5	24.8	0.20	63.9	27.0	0.20	459	0.00	0.00
	Pharmacy Dispensary	A6	23.0	0.09	57.3	24.8	0.66	717	0.00	0.00
	Pharmacy Store	A7	22.9	0.13	62.8	23.1	0.40	785	0.00	0.00
	Pediatric 1	A8	31.4	0.30	60.9	33.6	0.00	343	0.00	3.40
	Pediatric 2	A9	32.1	0.20	58.7	33.7	0.00	383	0.00	0.30
	X-ray 1	A10	27.7	0.12	56.9	28.7	0.00	422	0.00	0.00
	X-ray 2	A11	20.5	0.27	72.6	21.9	0.00	454	0.00	0.00

Table K-2: Indoor air contaminants and physical measurements in Kuala Kubu Hospital

Hospital	Department	Sampling Point	Thermal Comfort Parameter				Indoor Air Contaminant			
			Air Temperature (℃)	Velocity (m/s)	RH (%)	MRT (℃)	CO (ppm)	CO_2 (ppm)	HCOH (ppm)	TVOC (ppm)
Kuala Kubu (B)	Maternity ward 1	B1	30.0	0.06	59.9	31.1	3.70	857	0.06	0.27
	Maternity ward 2	B2	30.7	0.09	58.4	32.0	3.70	**1013**	0.07	0.25
	Hematology lab	B3	28.8	0.20	55.0	30.4	3.30	639	0.08	0.19
	Pharmacy	B4	24.5	0.12	53.8	25.9	2.50	762	0.05	0.21
	Medical ward	B5	27.5	0.43	52.6	29.5	3.20	900	0.06	0.22
	Pediatric ward	B6	32.0	0.22	56.2	33.2	2.60	624	0.05	0.21
	Hemeodalisis room	B7	29.7	0.11	53.3	31.1	2.60	700	0.08	0.15
	X-ray	B8	27.9	0.08	54.1	29.2	2.50	701	0.10	0.14

TableK-3: Indoor air contaminants and physical measurements in Sungai Buloh Hospital

Hospital	Department	Sampling Point	Thermal Comfort Parameter				Indoor Air Contaminant			
			Air Temperature (℃)	Velocity (m/s)	RH (%)	MRT (℃)	CO (ppm)	CO_2 (ppm)	HCOH (ppm)	TVOC (ppm)
Sungai Buloh (C)	Internal Pediatric	C1	22.6	0.12	63.6	23.2	0.00	736	0.00	0.28
	External Pediatric	C2	22.0	0.05	72.6	22.5	0.00	451	0.00	1.55
	Optalmology 1	C3	24.4	0.05	77.3	24.8	0.00	415	0.00	16.5
	Optalmology 2	C4	24.0	0.03	72.6	24.4	0.00	470	0.00	4.03
	Medical ward 1	C5	24.8	0.14	77.9	25.4	0.00	392	0.03	8.76
	Medical ward 2	C6	23.6	0.08	75.0	24.0	0.00	503	0.02	1.66
	Pharmacy 1	C7	24.5	0.05	71.7	25.0	0.76	464	0.00	1.66
	Pharmacy 2	C8	23.2	0.02	76.4	23.6	0.50	467	0.03	1.66
	Pathology 1	C9	22.3	0.16	69.4	22.9	0.10	342	0.03	0.29
	Pathology 2	C10	21.1	0.10	70.0	21.6	0.00	344	0.00	0.19
	Pathology 3	C11	20.3	0.11	73.1	20.8	0.00	365	0.00	0.21
	X-ray 1	C12	21.7	0.02	71.2	22.1	0.00	385	0.00	0.00
	X-ray 2	C13	21.5	0.09	74.4	22.0	0.00	393	0.00	0.00
	X-ray 3	C14	19.8	0.04	62.9	20.7	0.00	351	0.00	0.00
	Maternity ward 1	C15	22.5	0.05	69.1	23.3	0.00	347	0.00	0.00
	Maternity ward 2	C16	22.3	0.05	75.3	23.1	0.00	321	0.00	0.00

Table K-4: Indoor air contaminants and physical measurements in Selayang Hospital

Hospital	Department	Sampling Point	Thermal Comfort Parameter				Indoor Air Contaminant			
			Air Temperature (℃)	Velocity (m/s)	RH (%)	MRT (℃)	CO (ppm)	CO_2 (ppm)	HCOH (ppm)	TVOC (ppm)
Selayang (D)	Pathology 1	D1	23.1	0.02	62.1	23.5	0.18	470	0.00	0.00
	Pathology 2	D2	23.8	0.02	59.4	24.2	0.13	440	0.04	1.92
	Microbiology lab	D3	24.0	0.12	63.8	24.5	0.15	435	0.00	0.08
	IVU	D4	23.1	0.02	62.1	23.5	0.18	470	2.61	0.00
	Maternity ward 1	D5	25.8	0.06	67.8	26.6	0.01	418	0.00	2.61
	Maternity ward 2	D6	26.7	0.01	52.9	27.4	0.05	509	0.00	0.00
	Pharmacy 1	D7	22.9	0.13	56.7	23.4	0.30	623	0.00	0.00
	Pharmacy 2	D8	22.0	0.02	56.7	22.4	0.17	580	0.03	0.00
	Internal Pediatric	D9	23.6	0.03	63.4	24.0	0.04	828	0.00	0.62
	External Pediatric	D10	24.6	0.04	62.2	25.0	0.00	806	0.00	0.03
	CT scan	D11	23.3	0.08	61.2	23.8	0.37	515	0.00	0.00
	MRI	D12	23.3	0.08	61.4	23.7	0.24	479	0.00	0.00

APPENDIX L

Subjective Measurements in Four Hospitals

Table L-1: Subjective measurements in Banting Hospital

Total Survey: 12 persons

Banting Hospital (A)				
Composition of respondent follow location			Symptoms often experience	
Location	*Male*	*Female*	*Symptoms*	*Vote*
Pharmacy	1	1	Dry eyes	3
Pathology lab	3	4	Dry or irritated throats	3
Ward	0	3	Headaches	4
Composition of respondents follow gender			Noise irritation	4
Gender	*Quantity*		Sleepiness	6
Male	4		Difficulty concentrating	2
Female	8		Dizziness	3
Thermal Sensation Poll			Skin dryness, rash or itch	5
Thermal Sensation	Vote Quantity		Chest tightness or breathing difficulties	1
Hot	0		Person ever had asthmatic problems	0
Warm	1		Person ever suffered from sinusitis	3
Slightly warm	1		Person ever suffered from eczema	1
Neutral	4		Person currently a smoker	0
Slightly cool	2		Person wear contact lens	2
Cool	4			
Cold	0			

Banting Hospital (A)			
Cleanliness Satisfaction		Occupant Activity Level	
Unsatisfactory	1	Reclining	0
Medium unsatisfactory	0	Seated quite	3
Light unsatisfactory	1	Stand relaxed	1
Normal	4	Light activity	0
Light satisfactory	1	Medium activity	6
Medium satisfactory	3	High activity	2
Satisfactory	2		

Composition of respondent to Odour	
Odour detection	Quantity
YES	4
NO	2

Odours detect				
Cigarettes	Carpet	Stationary	Food	Others
-	-	-	1	5

Location	Air Movement						
	1 (Still)	2	3	4	5	6	7 (Draughty)
Pharmacy	0	1	0	0	1	0	0
Pathology	2	0	1	3	1	0	0
Wad	0	0	2	1	0	0	0
Total	**2**	**1**	**3**	**4**	**2**	**0**	**0**

Location	Air Quality						
	1 (Fresh)	2	3	4	5	6	7 (Stuffy)
Pharmacy	1	0	0	1	0	0	0
Pathology	1	2	0	3	1	0	0
Wad	1	0	0	2	0	0	0
Total	**3**	**2**	**0**	**6**	**1**	**0**	**0**
Location	1 (Odourless)	2	3	4	5	6	7 (Smelly)
Pharmacy	1	0	1	0	0	0	0
Pathology	1	2	0	3	1	0	0
Wad	0	1	1	1	0	0	0
Total	**2**	**3**	**2**	**4**	**1**	**0**	**0**
Location	1 (Clean)	2	3	4	5	6	7 (Dusty)
Pharmacy	2	0	0	0	0	0	0
Pathology	1	1	1	3	0	0	1
Wad	0	1	0	2	0	0	0
Total	**3**	**2**	**1**	**5**	**0**	**0**	**1**

Location	Acoustic						
	No noise from ventilation			Too much noise from ventilation			
	1	2	3	4	5	6	7
Pharmacy	2	0	0	0	0	0	0
Pathology lab	2	1	0	4	0	0	0
Wad	1	0	0	1	0	0	1
Total	**5**	**1**	**0**	**5**	**0**	**0**	**1**
Location	No other noise				Too much other noise		
Pharmacy	1	1	0	0	0	0	0
Pathology	1	2	0	3	1	0	0
Wad	0	1	0	1	0	1	0
Total	**2**	**4**	**0**	**4**	**1**	**1**	**0**

Location	Lighting						
	1 (Too dark)	2	3	4	5	6	7 (Too bright)
Pharmacy	0	0	1	0	1	0	0
Pathology	1	3	2	1	0	0	0
Wad	0	1	0	2	0	0	0
Total	1	4	3	3	1	0	0
Location	1 (Steady)	2	3	4	5	6	7 (Flickering)
Pharmacy	1	1	0	0	0	0	0
Pathology	1	2	3	1	0	0	0
Wad	0	1	1	1	0	0	0
Total	**2**	**4**	**4**	**2**	**0**	**0**	**0**
Location	1 (No glare)	2	3	4	5	6	7 (Too much)
Pharmacy	1	1	0	0	0	0	0
Pathology	2	2	1	2	0	0	0
Wad	0	1	1	1	0	0	0
Total	**3**	**4**	**2**	**3**	**0**	**0**	**0**
Location	1 (V.uniform)	2	3	4	5	6	7 (V. uneven)
Pharmacy	0	0	1	0	1	0	0
Pathology	1	1	2	0	1	1	1
Wad	1	0	1	1	0	0	0
Total	**2**	**1**	**4**	**1**	**2**	**1**	**1**
Location	1 (Satisfactory)	2	3	4	5	6	7 (Unsatisfactory)
Pharmacy	0	1	0	0	1	0	0
Pathology	1	2	0	1	2	1	0
Wad	2	0	0	1	0	0	0
Total	**3**	**3**	**0**	**2**	**3**	**1**	**0**

Table L-2: Subjective measurements in Kuala Kubu Hospital

Total survey: 37 persons

Kuala Kubu Hospital (B)				
Composition of respondent follow location			Symptoms often experience	
Location	*Male*	*Female*	*Symptoms*	*Vote*
Pharmacy	1	12	Dry eyes	7
X-ray	4	3	Dry or irritated throats	10
Maternity	0	5	Headaches	9
Pathology Lab	3	2	Noise irritation	4
Women ward	0	6	Sleepiness	8
Pediatric ward	0	1	Difficulty concentrating	0
Composition of respondents follow gender			Dizziness	1
Gender	*Quantity*		Skin dryness, rash or itch	6
Male	8		Chest tightness or breathing difficulties	1
Female	29		Person ever had asthmatic problems	0
Thermal Sensation Poll			Person ever suffered from sinusitis	1
Thermal Sensation	Vote Quantity		Person ever suffered from eczema	0
Hot	0		Person currently a smoker	1
Warm	2		Person wear contact lens	2
Slightly warm	2			
Neutral	20			
Slightly cool	10			
Cool	2			
Cold	1			

Kuala Kubu Hospital (B)			
Cleanliness Satisfaction		Occupant Activity Level	
Unsatisfactory	0	Reclining	1
Medium unsatisfactory	0	Seated quite	15
Light unsatisfactory	2	Stand relaxed	1
Normal	16	Light activity	6
Light satisfactory	8	Medium activity	14
Medium satisfactory	7	High activity	0
Satisfactory	4		

Composition of respondent to Odour	
Odour detection	Quantity
YES	10
NO	27

Odours detect				
Cigarettes	Carpet	Stationary	Food	Others
-	-	-	6	4

Location	Air Movement						
	1 (Still)	2	3	4	5	6	7 (Draughty)
Pharmacy	0	2	1	8	2	0	0
X-ray	0	1	1	3	2	0	0
Maternity	0	0	2	3	0	0	0
Pathology	0	1	1	2	0	1	0
Women ward	0	0	1	4	1	0	0
Pediatric	0	0	0	0	1	0	0
Total	**0**	**4**	**6**	**20**	**6**	**1**	**0**

Location	Air Quality						
	1 (Fresh)	2	3	4	5	6	7 (Stuffy)
Pharmacy	3	1	5	2	2	0	0
X-ray	0	1	2	3	1	0	0
Maternity	2	0	2	1	0	0	0
Pathology	1	1	0	2	0	1	0
Women ward	0	0	1	5	0	0	0
Pediatric	0	0	0	1	0	0	0
Total	**6**	**3**	**10**	**14**	**3**	**1**	**0**
Location	1 (Odorless)	2	3	4	5	6	7 (Smelly)
Pharmacy	3	0	7	1	2	0	0
X-ray	0	1	2	3	1	0	0
Maternity	0	2	3	0	0	0	0
Pathology	0	0	3	1	1	0	0
Women ward	0	0	1	5	0	0	0
Pediatric	0	0	0	0	0	1	0
Total	**3**	**3**	**16**	**10**	**4**	**1**	**0**
Location	1 (Clean)	2	3	4	5	6	7 (Dusty)
Pharmacy	3	1	5	2	2	0	0
X-ray	0	1	2	4	0	0	0
Maternity	2	1	2	0	0	0	0
Pathology	0	1	2	1	0	1	0
Women ward	0	0	1	5	0	0	0
Pediatric	0	0	0	0	0	1	0
Total	**5**	**4**	**12**	**12**	**2**	**2**	**0**

Location	Acoustic						
	No noise from ventilation						Too much noise from ventilation
	1	**2**	**3**	**4**	**5**	**6**	**7**
Pharmacy	3	1	2	4	2	1	0
X-ray	0	0	2	2	3	0	0
Maternity	0	2	0	0	0	0	3
Pathology	1	0	1	1	1	0	1
Women ward	0	4	1	0	1	0	0
Pediatric	0	0	0	0	1	0	0
Total	**4**	**7**	**6**	**7**	**8**	**1**	**4**
Location	No other noise						Too much other noise
Pharmacy	3	3	0	7	1	0	0
X-ray	0	0	1	3	1	2	0
Maternity	1	1	2	1	0	0	0
Pathology	1	1	2	0	1	0	0
Women ward	0	0	1	4	1	0	0
Paediatric	0	0	0	0	1	0	0
Total	**5**	**5**	**6**	**14**	**5**	**2**	**0**

Location	Lighting						
	1 (Too dark)	2	3	4	5	6	7 (Too bright)
Pharmacy	3	0	0	5	4	1	0
X-ray	0	0	2	5	0	0	0
Maternity	0	1	1	3	0	0	0
Pathology	0	0	0	2	3	0	0
Women ward	0	0	1	1	3	1	0
Pediatric	0	0	0	0	1	0	0
Total	**3**	**1**	**4**	**16**	**11**	**2**	**0**
Location	1 (Steady)	2	3	4	5	6	7 (Flickering)
Pharmacy	3	2	1	6	1	0	0
X-ray	0	0	2	4	0	1	0
Maternity	3	1	2	0	0	0	0
Pathology	0	0	1	2	2	0	0
Women ward	0	0	1	3	1	1	0
Pediatric	0	0	0	0	1	0	0
Total	**6**	**3**	**7**	**14**	**5**	**2**	**0**
Location	1 (No glare)	2	3	4	5	6	7 (Too much)
Pharmacy	3	0	2	8	0	0	0
X-ray	0	2	2	1	2	0	0
Maternity	2	1	0	2	0	0	0
Pathology	0	0	2	1	2	00	0
Women ward	0	0	1	4	1	0	0
Pediatric	0	0	0	0	0	1	0
Total	**5**	**3**	**7**	**16**	**5**	**1**	**0**
Location	1 (V.uniform)	2	3	4	5	6	7 (V. uneven)
Pharmacy	3	1	2	7	0	0	0
X-ray	0	0	1	1	3	2	0
Maternity	0	2	1	2	0	0	0
Pathology	0	0	2	1	2	0	0
Women ward	0	0	1	1	4	0	0
Pediatric	0	0	0	0	0	1	0
Total	**3**	**3**	**7**	**12**	**9**	**3**	**0**
Location	1 (Satisfactory)	2	3	4	5	6	7 (Unsatisfactory)
Pharmacy	3	1	2	7	0	0	0
X-ray	0	3	2	2	0	0	0
Maternity	0	3	0	2	0	0	0
Pathology	0	1	1	1	1	1	0
Women ward	0	0	1	2	2	1	0
Pediatric	0	0	0	0	0	1	0
Total	**3**	**8**	**6**	**14**	**3**	**3**	**0**

Table L-3: Subjective measurements in Sungai Buloh Hospital

Total survey: 36 persons

Sungai Buloh Hospital (C)				
Composition of respondent follow location			Symptoms often experience	
Location	*Male*	*Female*	*Symptoms*	*Vote*
Pharmacy	0	11	Dry eyes	10
Pathology lab	2	2	Dry or irritated throats	7
Radiology	4	9	Headaches	15
Pediatric	0	3	Noise irritation	9
Maternity ward	0	5	Sleepiness	12
Composition of respondents follow gender			Difficulty concentrating	0
Gender	*Quantity*		Dizziness	2
Male	6		Skin dryness, rash or itch	19
Female	30		Chest tightness or breathing difficulties	0
Thermal Sensation Poll			Person ever had asthmatic problems	1
Thermal Sensation	Vote Quantity		Person ever suffered from sinusitis	14
Hot	0		Person ever suffered from eczema	6
Warm	0		Person currently a smoker	0
Slightly warm	0		Person wear contact lens	4
Neutral	3			
Slightly cool	8			
Cool	9			
Cold	16			

Sungai Buloh (C)			
Cleanliness Satisfaction		Occupant Activity Level	
Unsatisfactory	1	Reclining	0
Medium unsatisfactory	0	Seated quite	4
Light unsatisfactory	0	Stand relaxed	4
Normal	15	Light activity	11
Light satisfactory	11	Medium activity	5
Medium satisfactory	5	High activity	12
Satisfactory	4		

Composition of respondents	
Odour detection	*Quantity*
Yes	16
No	20

Odours Detect				
Cigarettes	*Carpet*	*Stationary*	*Food*	*Others*
4	-	-	2	10

Location	**Air Movement Rating**						
	1 (Still)	2	3	4	5	6	7(Draughty)
Pharmacy	0	2	2	4	3	0	0
Pathology	0	0	0	1	1	1	1
Radiology	2	1	1	2	4	2	1
Pediatric	0	1	0	2	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**2**	**4**	**3**	**14**	**8**	**3**	**2**

Location	**Air Quality**						
	1(Fresh)	2	3	4	5	6	7(Stuffy)
Pharmacy	0	3	4	2	2	0	0
Pathology	0	0	1	1	2	0	0
Radiology	3	0	7	1	2	0	0
Pediatric	0	1	0	2	0	0	0
Maternity	0	0	1	2	2	0	0
Total	**3**	**4**	**13**	**8**	**8**	**0**	**0**
Location	1(Odorless)	2	3	4	5	6	7(Smelly)
Pharmacy	0	1	6	3	1	0	0
Pathology	0	0	1	1	2	0	0
Radiology	4	2	1	6	0	0	0
Pediatric	0	2	1	0	0	0	0
Maternity	0	0	1	1	3	0	0
Total	**4**	**5**	**10**	**11**	**6**	**0**	**0**
Location	1(Clean)	2	3	4	5	6	7(Dusty)
Pharmacy	0	4	3	4	0	0	0
Pathology	0	0	1	1	2	0	0
Radiology	3	4	5	1	0	0	0
Pediatric	0	2	0	1	0	0	0
Maternity	0	0	0	4	1	0	0
Total	**3**	**10**	**9**	**11**	**3**	**0**	**0**

Location	**Acoustics**						
	No noise from ventilation system				Too much noise from ventilation system		
	1	2	3	4	5	6	7
Pharmacy	1	2	1	5	0	1	1
Pathology	0	0	0	3	1	0	0
Radiology	2	4	1	4	0	1	1
Pediatric	0	2	1	0	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**3**	**8**	**3**	**17**	**1**	**2**	**2**
Location	No other noise					Too much other noise	
	1	2	3	4	5	6	7
Pharmacy	1	2	1	4	1	1	1
Pathology	0	0	0	2	1	0	1
Radiology	2	1	0	7	1	1	1
Pediatric	0	1	2	0	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**3**	**4**	**3**	**18**	**3**	**2**	**3**

Location	Lighting						
	1(Too Dark)	2	3	4	5	6	7(Too Bright)
Pharmacy	0	0	1	3	3	4	0
Pathology	0	0	0	0	0	3	1
Radiology	0	0	3	4	0	3	3
Pediatric	0	0	2	1	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**0**	**0**	**6**	**13**	**3**	**10**	**4**
Location	1(Steady)	2	3	4	5	6	7(Flickering)
Pharmacy	1	2	2	2	2	1	1
Pathology	0	1	1	1	1	0	0
Radiology	2	5	0	2	2	1	1
Pediatric	0	1	1	1	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**3**	**9**	**4**	**11**	**5**	**2**	**2**
Location	1(No glare)	2	3	4	5	6	7(Too much)
Pharmacy	0	1	2	6	0	1	1
Pathology	0	1	0	2	0	1	0
Radiology	0	2	3	8	0	0	0
Pediatric	0	0	2	1	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**0**	**4**	**7**	**22**	**0**	**2**	**1**
Location	1(V.uniform)	2	3	4	5	6	7(V. uneven)
Pharmacy	0	1	2	8	0	0	0
Pathology	0	0	0	3	0	1	0
Radiology	0	4	6	3	0	0	0
Pediatric	0	2	1	0	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**0**	**7**	**9**	**19**	**0**	**1**	**0**
Location	1(Satisfactory)	2	3	4	5	6	7 (Unsatisdfactory)
Pharmacy	0	3	3	4	0	0	1
Pathology	0	1	0	2	0	1	0
Radiology	2	6	2	3	0	0	0
Pediatric	0	1	2	0	0	0	0
Maternity	0	0	4	1	0	0	0
Total	**2**	**11**	**11**	**10**	**0**	**1**	**1**

Symptoms (Air Quality Effects)	Pharmacy	Pathology	Radiology	Pediatric	Maternity
Dry eyes	4	2	4	0	0
Dry or irritated throat	1	0	6	0	0
Headaches	4	3	6	2	0
Noise irritation	5	2	2	0	0
Sleepiness	4	2	5	1	0
Difficulty concentrating	0	0	0	0	0
Dizziness	0	1	1	0	0
Skin dryness, rash or itch	1	4	9	1	4
Chest tightness or breathing difficulty	0	0	0	0	0

Table L-4: Subjective measurements in Selayang Hospital

Total survey: 24 persons

Selayang Hospital (D)				
Composition of respondent follow location			Symptoms often experience	
Location	*Male*	*Female*	*Symptoms*	*Vote*
Pharmacy	1	6	Dry eyes	5
Pediatric	0	3	Dry or irritated throats	6
Maternity	5	0	Headaches	4
Pathology	0	4	Noise irritation	3
Radiology	3	2	Sleepiness	7
Composition of respondents follow gender			Difficulty concentrating	4
			Dizziness	1
Gender	*Quantity*		Skin dryness, rash or itch	16
Male	9		Chest tightness or breathing difficulties	1
Female	15			
Thermal Sensation Poll			Person ever had asthmatic problems	0
Thermal Sensation	Vote Quantity		Person ever suffered from sinusitis	3
Hot	0		Person ever suffered from eczema	4
Warm	0		Person currently a smoker	1
Slightly warm	0		Person wear contact lens	4
Neutral	3			
Slightly cool	4			
Cool	5			
Cold	12			

Selayang (D)			
Cleanliness Satisfaction		Occupant Activity Level	
Unsatisfactory	0	Reclining	0
Medium unsatisfactory	0	Seated quite	1
Light unsatisfactory	0	Stand relaxed	8
Normal	6	Light activity	9
Light satisfactory	9	Medium activity	3
Medium satisfactory	5	High activity	4
Satisfactory	4		

Composition of respondents	
Odour detection	*Quantity*
Yes	9
No	15

Odours Detect				
Cigarettes	*Carpet*	*Stationary*	*Food*	*Others*
2		-	4	3

Location	**Air Movement Rating**						
	1 (Still)	2	3	4	5	6	7(Draughty)
Pharmacy	2	0	1	2	1	0	0
Pathology Lab	0	0	0	1	3	0	0
Radiology	0	1	2	3	0	0	0
Pediatric	0	1	0	2	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**2**	**2**	**3**	**13**	**4**	**0**	**0**

Air Quality							
Location	1(Fresh)	2	3	4	5	6	7(Stuffy)
Pharmacy	1	1	1	3	0	0	0
Pathology	0	0	0	1	0	3	0
Radiology	0	2	3	1	0	0	0
Pediatric	0	1	0	2	0	0	0
Maternity	0	0	1	2	2	0	0
Total	**1**	**4**	**5**	**9**	**2**	**3**	**0**
Location	1(Odorless)	2	3	4	5	6	7(Smelly)
Pharmacy	1	1	1	2	0	1	0
Pathology	0	0	0	1	0	3	0
Radiology	0	4	1	0	1	0	0
Pediatric	0	2	1	0	0	0	0
Maternity	0	0	1	1	3	0	0
Total	**1**	**7**	**4**	**4**	**4**	**4**	**0**
Location	1(Clean)	2	3	4	5	6	7(Dusty)
Pharmacy	1	1	2	2	0	0	0
Pathology	0	0	0	0	3	1	0
Radiology	0	3	0	0	2	1	0
Pediatric	0	2	0	1	0	0	0
Maternity	0	0	0	4	1	0	0
Total	**1**	**6**	**2**	**7**	**6**	**2**	**0**

Location	**Acoustics**						
	No noise from ventilation system				Too much noise from ventilation system		
	1	2	3	4	5	6	7
Pharmacy	0	0	1	3	2	0	0
Pathology	0	0	0	4	0	0	0
Radiology	0	0	3	1	2	0	0
Pediatric	0	2	1	0	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**0**	**2**	**5**	**13**	**4**	**0**	**0**
Location	No other noise						Too much other noise
	1	2	3	4	5	6	7
Pharmacy	0	0	4	1	1	0	0
Pathology	0	0	0	4	0	0	0
Radiology	0	2	1	3	0	0	0
Pediatric	0	1	2	0	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**0**	**3**	**7**	**13**	**1**	**0**	**0**

Location	Lighting						
	1(Too Dark)	2	3	4	5	6	7(Too Bright)
Pharmacy	0	1	0	4	0	1	0
Pathology	0	0	0	0	1	3	0
Radiology	0	1	2	2	1	1	0
Pediatric	0	0	2	1	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**0**	**1**	**4**	**12**	**2**	**5**	**0**
Location	1(Steady)	2	3	4	5	6	7(Flickering)
Pharmacy	0	2	1	3	0	0	0
Pathology	0	0	0	0	3	1	0
Radiology	1	0	3	3	0	0	0
Pediatric	0	1	1	1	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**1**	**3**	**5**	**12**	**3**	**1**	**0**
Location	1(No glare)	2	3	4	5	6	7(Too much)
Pharmacy	0	1	1	3	0	1	0
Pathology	0	0	0	0	3	1	0
Radiology	1	0	1	3	1	0	0
Pediatric	0	0	2	1	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**1**	**1**	**4**	**12**	**4**	**2**	**0**
Location	1(V.uniform)	2	3	4	5	6	7(V. uneven)
Pharmacy	0	1	1	4	0	0	0
Pathology	0	0	0	0	3	2	0
Radiology	0	0	1	3	2	0	0
Pediatric	0	2	1	0	0	0	0
Maternity	0	0	0	5	0	0	0
Total	**0**	**3**	**3**	**12**	**5**	**2**	**0**
Location	1 (Satisfactory)	2	3	4	5	6	7 (Unsatisdfactory)
Pharmacy	1	1	0	3	0	1	0
Pathology	0	0	0	0	3	1	0
Radiology	0	3	2	1	0	0	0
Pediatric	0	1	2	0	0	0	0
Maternity	0	0	4	1	0	0	0
Total	**1**	**5**	**8**	**5**	**3**	**2**	**0**

Symptoms (Air Quality Effects)	Pharmacy	Pathodology	Radiology	Pediatric	Maternity
Dry eyes	3	1	1	0	0
Dry or irritated throat	3	0	3	0	0
Headaches	1	1	0	2	0
Noise irritation	3	0	0	0	0
Sleepiness	3	0	3	1	0
Difficulty concentrating	4	0	0	0	0
Dizziness	0	1	0	0	0
Skin dryness, rash or itch	5	4	2	1	4
Chest tightness or breathing difficulty	1	0	0	0	0